THE UNIVERSITY OF ALBERTA

RELATIONSHIP BETWEEN SOILS AND GROUNDWATER IN FIELD MAPPING NEAR VEGREVILLE, ALBERTA

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Relationship between soils and groundwater in field mapping near Vegreville, Alberta," submitted by Leonard Alexander Leskiw, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

Field mapping was conducted in the Vegreville area in order to determine the relationship between soils and natural groundwater movement.

Hydraulic head distribution, groundwater chemistry, and surficial features of groundwater flow were examined and were shown to indicate the presence of local and intermediate groundwater flow systems. It was concluded that soils of the Chernozemic Order and some of the Gleysolic Order which were mapped indicate groundwater recharge conditions. Groundwater discharge conditions were indicated by the presence of Solonetzic, Regosolic, and some Gleysolic soils.

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HYDROLOGICAL PROFILES

I. INTRODUCTION

The demand for knowledge regarding our natural resources has initiated the trend towards the use of interdisciplinary approaches in environmental studies.

Field mapping procedures for obtaining inventories of our soils and groundwater resources have been developed and used independently but few studies have been conducted in Alberta to relate these and thus provide a better understanding of each.

The main objective of this project was to determine whether soil genesis and groundwater movement are related and, if they are, to show the relationships that do exist. To achieve this purpose the investigation comprised:

(1) A detailed soil survey of a selected area.

This includes sampling of representative soils and performing of routine laboratory analyses in order to characterize the mapping units.

(2) An inspection and sampling of farm wells to establish hydraulic head distribution and to determine groundwater chemistry.

(3) A mapping of surficial groundwater features, other than soils, which are believed to be associated with natural groundwater recharge and discharge.

(4) A final evaluation to correlate the results obtained from (1), (2), and (3).

In addition, piezometer nests were installed in order to obtain measurements of fluid potential which are to be used to determine the actual groundwater flow paths. These could then be compared to the flow paths predicted from field mapping.

A microbiological investigation of two springs was also conducted.

II. LITERATURE REVIEW

General Statement

A review of the literature affords the construction of a realistic model that reveals the relationships between groundwater and soils which might be expected in the present study.

The aspects of groundwater that are considered include the natural distribution and movement of groundwater, groundwater chemistry, and surficial features of groundwater flow. With regard to soils, both the characteristics of soil individuals and the geographical distributions of them are significant.

Natural Movement of Groundwater

A simple yet entire flow system theoretically exists along one flank of a single symmetrical drainage basin, provided that the land surface is uniformly sloping and the porous medium is homogeneous and isotropic. The drainage basin is composed of two areas -- the recharge area which is upslope from the midline and the discharge area which is downslope from the midline (Figure 1). Consequently, the downslope half of the valley is the discharge area proper and groundwater discharge is not concentrated in the valley bottom.

The belt of water table fluctuation must widen across the valley flank from the valley bottom to the divide as a result of the distribution of recharge and discharge areas (Tóth, 1962).

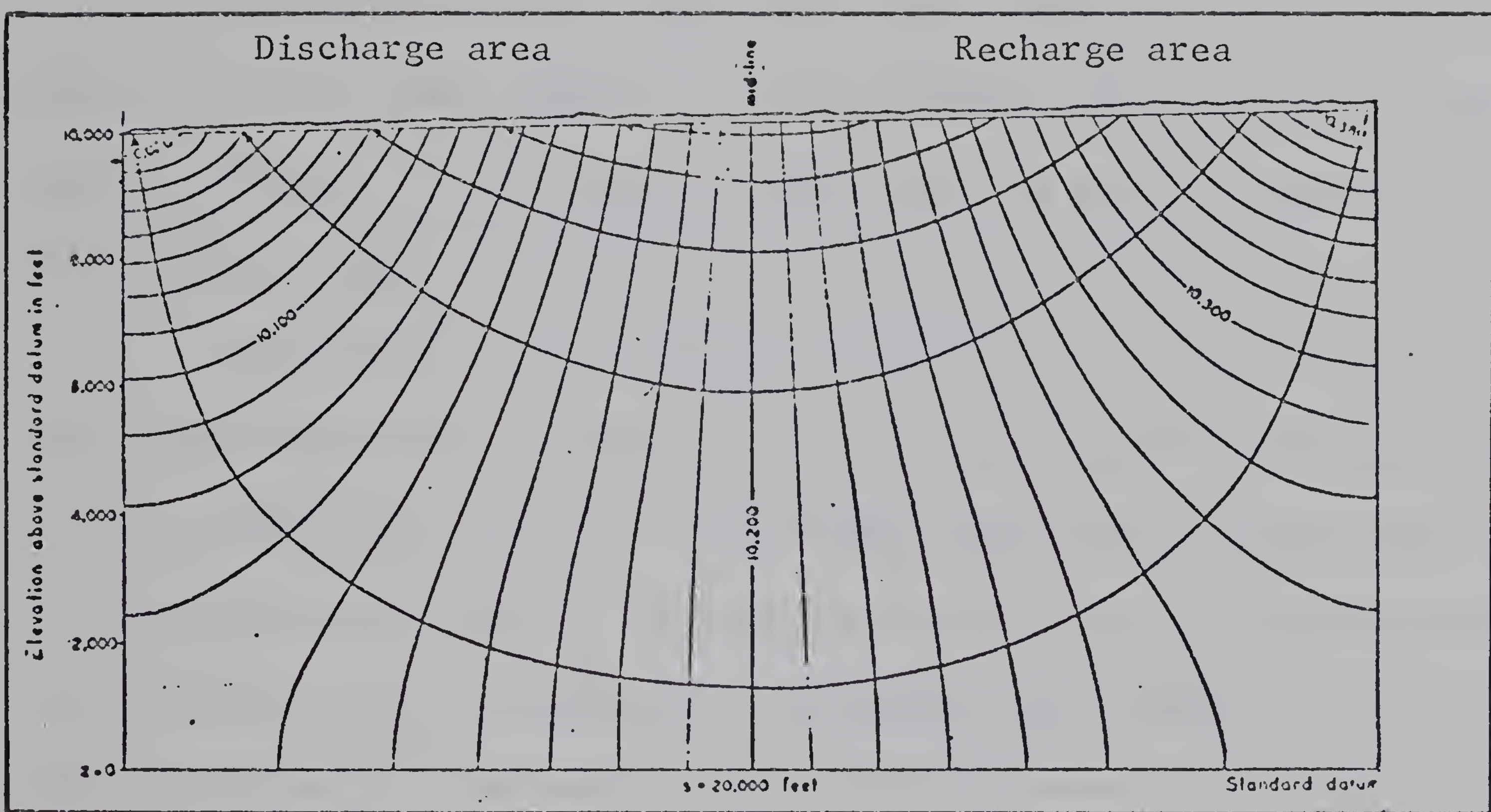


Figure 1. Distribution of recharge and discharge areas with respect to the hingeline (midline) (Modified after Tóth, 1962, Figure 3).

However, topographic irregularities may exist and have their own associated flow systems so that several flow systems may be superimposed on one another (Tóth, 1963). Three distinctly different types of flow systems can occupy a basin, namely, local, intermediate, and regional systems (Figure 2).

Areas of downward flow (recharge) are characterized in the field by a lowering of water levels with increasing well depth, whereas, depending on the local slope of the land surface, water levels may drop, remain constant, or rise with increasing depth in areas of upward flow (Tóth, 1968, p. 28).

In addition to the effects of topography, locally observed anomalously low or high piezometric pressures may result from the presence of high permeability lenses in an otherwise homogeneous medium (Tóth, 1963). In interlayered materials of contrasting permeabilities, flow direction will be mainly vertical within the low permeability materials (K = 1, Figure 3) and mainly horizontal within the high permeability materials (K = 10, Figure 3), as demonstrated by Freeze and Witherspoon (1967). Therefore, a high permeability lense, like a local topographic high, may create local recharge and discharge areas. This has also been observed in field studies where piezometer nests were used (Meyboom *et al.*, 1966).

Groundwater Chemistry

The chemical quality of groundwater is determined by the kind and amount of chemical matter dissolved in the water.

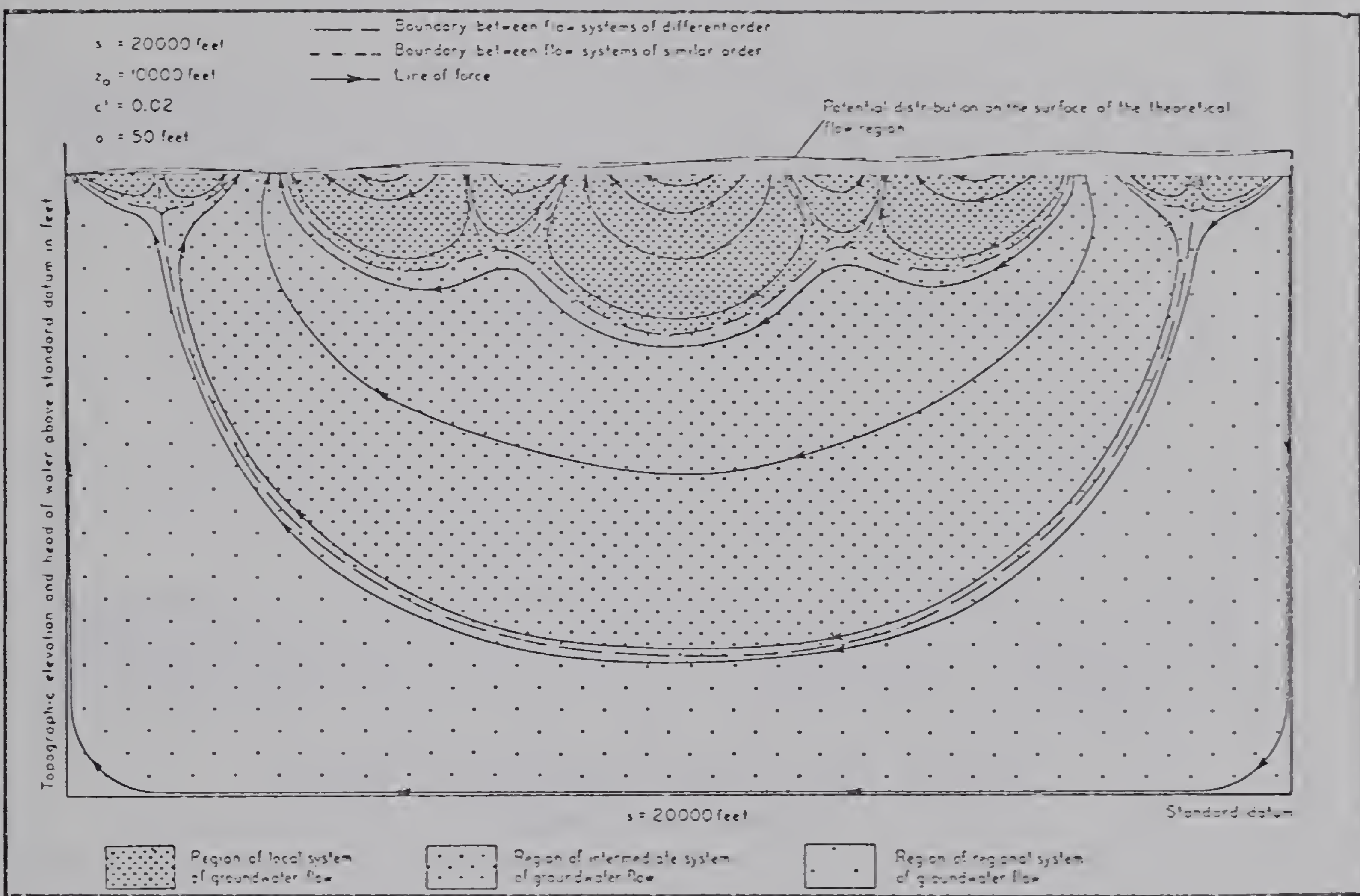
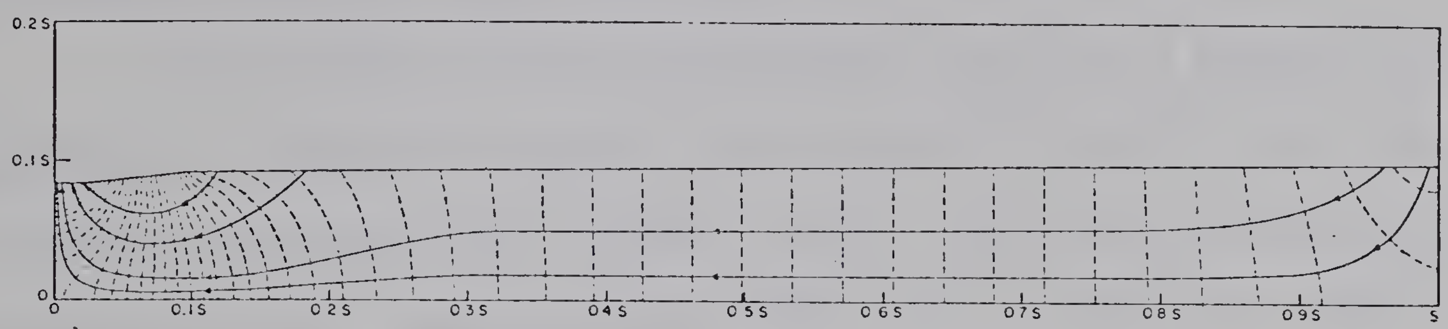
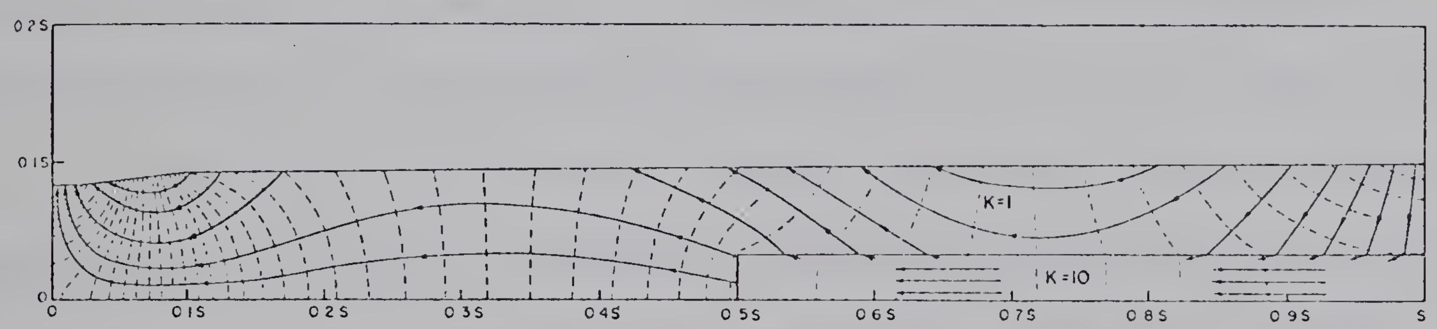


Figure 2. Theoretical flow distribution in a composite, homogeneous, and isotropic drainage basin (after Tóth, 1963).



Regional groundwater flow through homogeneous isotropic medium



Regional groundwater flow through partial layers and lenses

Figure 3. Altered flow patterns due to permeability contrasts (After Freeze and Witherspoon, 1967).

The primary controls on the amount of dissolved solids in groundwater are the chemical character of the water as it enters the zone of saturation, the distribution, solubility, and adsorption capacity of the minerals in the deposits; and the time in which the water is in contact with the rocks (Back, 1966). Time is dependent on the porosity and permeability of the rocks and the flow path of the water.

As the length of flow path increases, there is a tendency for groundwater to change its dominant cation from Ca^{++} to Mg^{++} to Na^{+} and its dominant anion from HCO_3^- to SO_4^{--} to Cl^-. There is an increase in the amount of total dissolved solids (TDS) as well (Chebotarev, 1955).

These changes in chemical composition of the groundwater are caused by one or more of the following: (a) solution of mineral matter, (b) ion exchange, (c) reduction of sulfates, and (d) other chemical reactions between the water and its environment (Maclay and Winter, 1967).

As a result of the above factors, one would expect groundwater flow patterns of different magnitude to have chemically different waters. For example, water in local flow systems may have primarily Ca^{++} and HCO_3^- ions and low amounts of TDS (total dissolved solids), whereas water in intermediate flow systems may have primarily Na^{+} and SO_4^{--} ions and moderate amounts of TDS.

The above relationships between groundwater chemistry and groundwater flow are supported by field observations, made in areas similar to that of this study, by Meyboom (1960), Tóth (1966a, 1966b, 1968), Tokarsky (1967), Clissold (1967), Rozkowski (1967), and Maclay and Winter (1967).

Surficial Features of Groundwater Flow

As a consequence of the movement and chemical properties of groundwater a number of observable phenomena may be present within a basin. These may be classified and used to interpret or predict areas of groundwater recharge and discharge.

The classification of observed phenomena used in groundwater mapping in a Prairie environment (Tóth, 1966a) is presented in Table 1. These features (Table 1) are defined and their significance is discussed briefly as follows:

A spring is defined as a place where a flow of water, issuing through and opening in rock or soil is discernible (Tóth, 1966a). A seepage is a diffuse discharge of groundwater in the liquid state to the land surface at an average rate equal to or exceeding that of the local evapotranspiration (Tóth, 1966a). These features are both unmistakable signs of upward moving groundwater and, therefore, are found only in discharge areas.

The groundwater level is that position in space to which groundwater rises in an open hole under its natural potential (Tóth, 1966a). It can be directly observed in water wells, at springs, and at other natural or artificial depressions in the land surface which obtain their water from the zone of saturation rather than from surface runoff. The observed water levels may be used for the construction of "water-level maps" and "hydraulic cross sections" to establish a three dimensional picture of the fluid potential distribution within the groundwater regime.

Table 1. Classification of Field Phenomena (after Tóth, 1966a)

1. Features pertaining to the environment:

   a. climate; b. relief; c. geology.

2. Features pertaining to water:

   a. aspects of the actual presence and of the physical and chemical properties of water.

   b. aspects associated with the presence or absence and with the physical and chemical properties of water.

Features classified under group 2.a.

- springs
- seepages
- groundwater levels
- flowing wells
- chemical quality of water (distribution of the chemical components)
- physical quality of water (temperature, turbidity, etc.)

Features classified under group 2.b.

- natural vegetation
- salt precipitates
- "burnt crops"
- "soapholes"
- moist depressions
- dry depressions
- man-made objects and local reports

A flowing well is an artificial hole in the ground in which water from the saturated zone rises above the land surface owing to its natural fluid potential (Tóth, 1966a). It, too, is interpreted as a point of groundwater discharge.

Chemical quality of waters is determined by laboratory analysis of water samples collected from springs, wells, and surface waters throughout the area. Maps may be prepared to show the areal distribution of various chemical constituents in the waters.

The properties that determine the physical quality of water include color, odor, temperature, and turbidity (Tóth, 1966a). However, in most cases no major conclusions regarding groundwater flow can be derived from them.

One of the most useful readily observable features used in groundwater mapping is the natural vegetation. Of course, for each area one works in, one must become thoroughly familiar with the species that may indicate differences in water quantity and quality.

Plants adapted to different degrees of water saturation in the soil are divided into three major types; halophytes, mesophytes, and xerophytes (Clements, 1920). The term phreatophytes includes some specialized species of each of the above types (Robinson, 1958; Meyboom, 1967a). Phreatophytes refers to those plants "that habitually obtain their water supply from the zone of saturation, either directly or through the capillary fringe" (Meinzer, 1927). Three examples of common phreatophytes are willow (*Salix* sp.), baltic rush (*Juncus balticus*), and red samphire (*Salicornia rubra*). These plants indicate a shallow depth

to water table and at least a very local zone of groundwater discharge.

Plant indicators of water quality may be classified as halophytes, i.e., those plants adapted to live on saline soil (Warming,[1] 1909), and glycophytes, i.e., those plants not adapted to live on either saline or alkaline soil (Stocker,[1] 1928). Depending on the degree of saturation, halophytes can be subdivided into those adapted to hydric (completely saturated) conditions and those adapted to mesic (moist) conditions. Halophytes cannot grow on physically dry soil because of the physiological drying effect of excess soluble salts. Examples of hydric halophytes occurring in the Oak River Basin, Manitoba, (Lissey, 1968) are prairie bulrush (*Scirpus paludosus*), Baltic rush (*Juncus Balticus*), and great bulrush (*Scirpus validus*). Mesic halophytes found include foxtail (*Hordeum jubatum*) and gumweed (*Grindelia perennis*).

While single species may be used as indicators, a much more precise estimate of water quality and water quantity can usually be obtained by using the plant communities as indicators (Lissey, 1968). The principle of using the community rather than a single species results from the preference certain plant species have for certain environmental factors. For example, a particular factor, such as salt content, may be near the lower limit of endurance for one species and near the upper limit of endurance for another so that the two species living together indicate relatively specific conditions.

In a hydroecological survey of sloughs (Lissey, 1968) it was observed that sloughs interpreted to indicate recharge have few concentric zones of glycophytes with a rapid transition from the central wet area to the adjacent dry upland. On the other hand, sloughs indicating

[1] According to Lissey (1968).

discharge have a number of concentric zones of halophytes with a gradual transition from the central wet zone to the adjacent dryland.

Salt precipitates and burnt crops occur where there is shallow groundwater containing high amounts of salt (eg. Na_2SO_4). The salt precipitates result from evaporation of the mineralized water. Burnt crops result from the adverse effects of the salt on crop growth.

A 'soaphole' as defined by Tóth (1966a) is a part of the land surface characterized by a local weakness of limited extent underlain by a viscous admixture of sand, silt, clay, and water. Different types of soapholes have been observed but all are situated in areas of upward-moving groundwater.

Another important phenomena that is very useful in groundwater mapping is the moist depression, commonly known as a pothole, slough, or marsh. "The main features, not all of which are necessarily present at each depression, are open water or an excessively moist, commonly marshy bottom; a ring-shaped pattern of growth of phreatophytic trees and shrubs (willow, poplar, etc.); the presence and a possible concentric pattern of growth of other phreatophytes (rushes, sedges, etc.); and salt precipitates" (Tóth, 1966a).

Tóth (1966a) described highland-type and lowland-type moist depressions in the Trochu area which correspond to Lissey's (1968) recharge and discharge sloughs, respectively, as discussed in relation to natural vegetation. In his hydroecological classification of sloughs, Lissey (1968) recognized six classes: fast recharge, slow recharge, fast fresh discharge, slow fresh discharge, fast saline discharge, and slow saline discharge.

Dry depressions which are similar in size and shape to the "moist depressions" described above have been observed in the Trochu area (Tóth, 1966a). The dry depressions lack characteristic features associated with moist conditions. Their dryness is attributed to the fact that they are situated on the highest portions of the area and are therefore in a position relative to groundwater flow systems that prevents them from receiving any contribution from groundwater. As a result, they are interpreted as being indicative of downward flow of groundwater (Tóth, 1966a).

Man-made objects observed near Trochu (Tóth, 1966) include pipes and troughs at springs for use by cattle, abandoned wooden cribbings used in spring development, and cement plugs used to control flowing wells or flowing siesmic shot-holes. Such objects may yield information on the groundwater regime but must be interpreted along with other associated features.

Thus, there are definite features which suggest groundwater recharge conditions and definite features which suggest groundwater discharge conditions. These must be located and identified in the field and when the locations are plotted on a map, areas of recharge and discharge can usually be outlined.

Soils as Related to Groundwater Flow

General Relationship

Scientific research dealing with the origin of solonetzic soils and the factors affecting salinization has contributed much of the

information available relating pedogenesis to natural groundwater flow. The characteristics of individual soil types as well as the geographical distribution and association of various soil individuals are the main factors to be considered in any soil study related to groundwater flow.

Salt accumulation in soil individuals is affected chiefly by groundwater, and the depth to the water table is critical (Muratova, 1958). His observations show: (1) when the groundwater comes within less than approximately 3 feet of the surface, strong surface salinization may result; (2) when the water table is between 4 and 6 feet, approximately, there is strong salinization in the top 3 feet of the soil rather than at the soil surface; and (3) when the water table is below about 6 feet, there is a sharp decrease in the extent of salinization of the top 3 feet of soil.

While the depth to water table is critical, the chemical quality of the water at the water table is equally important. The kinds of salts that accumulate in the soil are directly related to the kinds of salts present in the groundwater. The latter is determined mainly by the factors governing groundwater flow and groundwater chemistry as discussed earlier. As a result, there exist natural areas characterized by three basic types of salt accumulation in soils and groundwater, namely, carbonate, sulfate, and chloride (Muratova, 1958).

Observed Relationships

It was concluded in the Edmonton area (Pawluk, Dumanski, and Tóth, 1969) that: (1) the Orthic Black Chernozem and Solodic Black Chernozem occur in either a midline or recharge area; (2) the Black Solod

appears to be in an area of groundwater recharge; (3) the Black Solonetz is located in the lower portions of the midline area or highest parts of a discharge area; and (4) the Saline Black Solonetz occurs in a groundwater discharge area. These observations indicate an expected increase in salinity within the soil pedon corresponding to a change from groundwater recharge to groundwater discharge conditions.

Bettenay et al. (1964) studied factors involved in increasing salinity following land clearing in a typical valley in the Western Australian wheat belt. The above authors concluded that salinity is associated with a three-component hydrologic system involving surface, soil, and aquifer waters. A hydrologic cycle and the soil associations occurring in the valley are represented in Figure 4.

The general salt contents of the soils in the associations (Figure 4) are indicated in the following quotation. "The concentration of salt in the surface of all soils, except those of the Stirling association, is low. In the Ulva soils salinity is associated with seepage spots and may reach 1% sodium chloride near the surface. On the Booran pediments, particularly in situations close to breakaways, similar high levels may occur. Soils of the Stirling association usually contain about 1% of sodium chloride but in salt pans levels may reach 3%. In the Meredin, Belka, and Hines Hill soils salts increase with depth and levels of about 1/2% sodium chloride are reached at 1 - 2 feet" (Bettenay et al., 1964, p. 201-202).

It is evident that the soils with high salt contents are located in groundwater discharge positions. The highest salt content

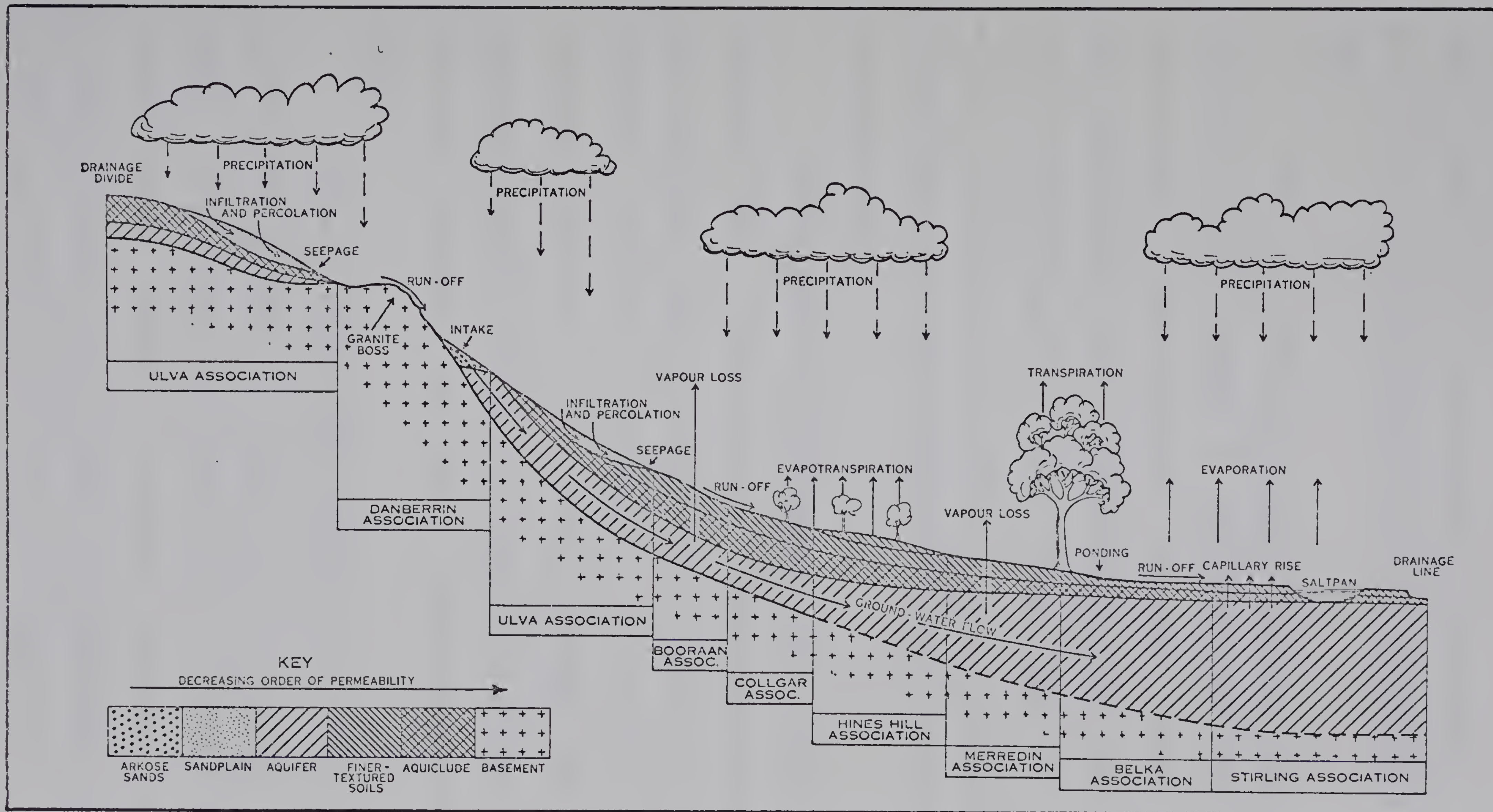


Figure 4. Hydrologic cycle in the Belka valley (after Bettenay et al., 1964).

occurs in soils at the lowest portion of the valley -- this corresponds to the discharge of groundwater from the comparatively longest flow paths.

This study (Bettenay et al., 1964) also shows that field surveys may indicate changes in equilibrium conditions between groundwater and soils. For example, the increases in amounts of soil water after clearing were shown to affect salinity by: firstly, increasing the area and duration of capillary contact between the confined aquifer and the soil surface in the valley floors; and secondly, leading to the development of saline-seepage spots in the coarse-textured soils on the valley sides.

Salinization in the Hungarian Danube Valley is described by Várallyay (1968). He found definite relationships between relief, soil type, groundwater depth, and groundwater chemistry as shown in Figure 5 and Table 2. Várallay suggested that, as with all salt affected soils in Hungary, those in the Danube Valley developed under the influence of groundwater and the accumulation of their considerable salt reserve had taken place mainly as a consequence of hydrological and hydrogeological factors.

Greenlee (1966, 1968) studied salt accumulation in soils resulting from groundwater seepage in the Vulcan region of southwestern Alberta. He concluded that bedrock and to a lesser extent till, were the salt sources. Studies of groundwater movement suggested both regional and local groundwater flow systems. An interesting result of the study was that the extensive salinization throughout the study area was of recent occurrence, no solonetzic morphological features were present,

Table 2. Relief, Soil Type, Average Depth of Water Table and Chemical Composition of the Groundwater in the Hungarian Danube Valley (after Várallyay, 1968).

Soil type	Height above sea level m	Average depth of the water table m	Salt content of ground water g/l	Salt composition of ground water
Recent alluvial soil	94– 97	2–2·5	0·3– 0·5	$Ca\text{-}HCO_3$
Meadow chernozem	97–100	3–4	1·0– 2·0	$Na\ (Ca)\text{-}HCO_3\ (Cl)$
Meadow soil, meadow alluvial soil	95– 97	2–3	1·0– 2·0	$Na\text{-}HCO_3$
Solonchak-solonetz, Calcareous solonetz	94– 95	1–2	2·0– 5·0	$Na\text{-}HCO_3$
Solonchak	93– 94	0·5–1·2	5·0–10·0	$Na\text{-}HCO_3\ (Cl)$

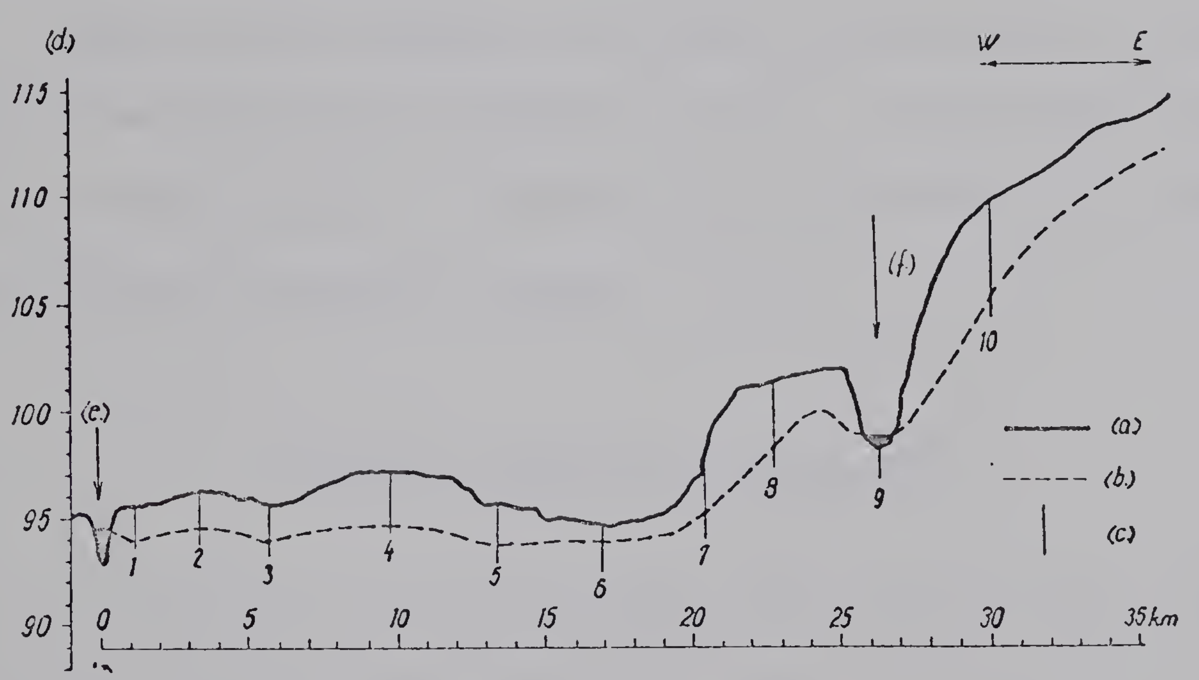


Fig. 1.—Correlation of relief, average depth of water table and genetic soil type in the Hungarian Danube Valley. (a) soil surface, (b) water table, (c) location of profiles, (d) height above sea level m, (e) Danube, (f) temporary water-logging. 1. Recent alluvial soil, 2. Humus alluvial soil, 3. Calcareous, solonchakized, shallow meadow solonetz, 4. Meadow alluvial soil, 5. Solonchak-solonetz, 6. Solonchak, 7. Solonetzic meadow soil, 8. Humus sandy soil, 9. Marshy meadow soil, 10. Humus sandy soil.

Figure 5. Correlation of relief, average depth of water table and genetic soil type in the Hungarian Danube Valley (after Várallyay, 1968).

except in the lowest topographic positions where salinized Solonetz soils occurred.

Summary of the Literature Review

A drainage basin is comprised of a recharge area in which groundwaters move downward and have low TDS, and a discharge area in which groundwaters move upward and have high TDS. The ions that make up the TDS and the absolute amount of TDS are determined by chemical composition of the geologic material and the time in which the water is in contact with the rocks.

Soils in the recharge area reflect the presence of non-saline groundwater and fluctuating groundwater levels. In the discharge area, soils reflect the presence of shallow, saline groundwater and comparatively stable groundwater levels.

Previous Work in the Study Area

A soil survey of the Wainwright and Vermilion Sheets was conducted by Wyatt et al. (1944). The soils that were mapped in the present study area include the Shallow Black, Black Zonal, Shallow Black Solonetz, and Black Solonetz.

A summary of groundwater information for east-central Alberta, published by LeBreton (1963), is applicable to the present study area. In general, the till that overlies the bedrock throughout the entire area is a poor source of groundwater supply and is suited largely to meet

domestic requirements only. The chemical quality of the groundwaters is relatively saline as TDS commonly exceed 1,000 parts per million.

III. PHYSIOGRAPHY

Location

The area under study is located east of the Vermilion River, northeast of Vegreville, Alberta (Figure 6a). Figure 6b also shows the legal location of the area which represents approximately 24,000 acres.

Initially the site was selected by Dr. Tóth of the Research Council of Alberta and Dr. Pawluk from the University of Alberta. A cursory examination of the area indicated a number of interesting groundwater phenomena and soil associations. It was considered that the study area was not unique in its geologic, climatologic, and physiographic aspects so that the results of the investigation would be applicable elsewhere. The size of the area was chosen so as to present an uncomplicated, yet complete picture of the relation between groundwater flow and soil pedogenesis.

Climate

Precipitation and temperature data for Vegreville, and precipitation data for Ranfurly and Warwick are presented in Table 3. Table 4 shows selected climatic data from May 1 to September 30 for Vegreville and Ranfurly.

The mean monthly high temperature, 62°F, and the maximum mean monthly precipitation, 3 inches, occur during July. For the period May to September, May has the lowest water deficiency and July the highest. For the same period, total precipitation is 10 to 12 inches and potential

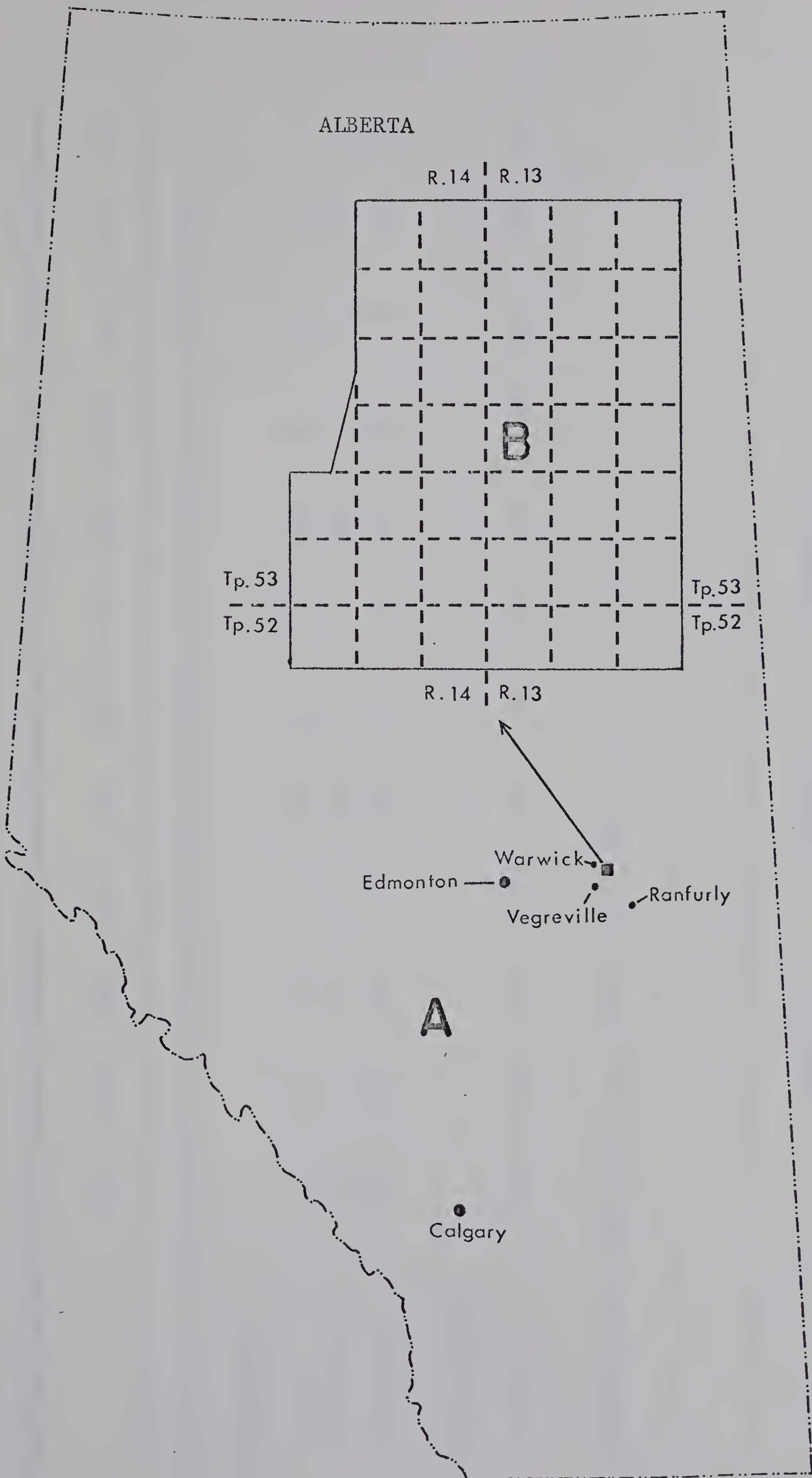


Figure 6a. Project area location map (Alberta).
Figure 6b. Orientation map of project area (inset).

Table 3. Climatic Data for Ranfurly, Warwick, and Vegreville

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Monthly and Annual Averages of Temperature (°F) and Precipitation for Vegreville (1958-1970)*												
<u>Temperature</u>												
Mean	1	9	20	38	50	58	62	58	50	37	20	5
Mean max.	40	41	51	67	82	86	89	86	79	70	52	41
Mean min.	-38	-32	-18	11	22	32	37	32	24	9	-16	-30
<u>Precipitation</u>												
Inches	0.60	0.57	0.30	0.53	1.36	2.48	3.00	2.59	1.62	0.71	0.54	0.51

Average Yearly Frost-free Days (below 29^{o}F, 1958-1970) = 115 days

Annual Averages of Precipitation for Ranfurly, Warwick, and Vegreville (1963-1970)*

	Ranfurly	Warwick	Vegreville
Inches	15.3	16.1	14.1

* Calculated from data obtained from Vegreville CDA Station.

Table 4. Selected Climatic Data for Ranfurly and Vegreville (after MacIver, 1970)

	May	June	July	Aug.	Sept.
Ranfurly					
Mean Temperature (F)	50.0	57.0	61.9	59.5	49.7
Precipitation (in.)	1.4	2.7	3.0	3.1	1.7
Potential Evapotranspiration (in.)	3.0	4.1	4.8	4.1	2.4
Actual Evapotranspiration (in.)	3.0	3.6	3.5	3.0	1.7
Water Deficiency (in.)	0.0	0.5	1.3	1.1	0.7
Vegreville					
Mean Temperature (F)	49.3	55.5	59.4	58.6	49.0
Precipitation (in.)	1.3	2.6	3.0	2.9	1.5
Potential Evapotranspiration (in.)	3.2	4.0	4.6	4.0	2.5
Actual Evapotranspiration (in.)	3.2	3.1	3.0	3.0	1.7
Water Deficiency (in.)	0.0	0.9	1.6	1.0	0.8

Selected Seasonal Normals (May 1 to Sept. 30, 1954 to 1968)

Temperature ^{o}F			Precipitation	Potential
Mean	Max.	Min.	(in.)	Evapotranspiration (in.)
54-58	66-70	42-46	10-12	18-19

evapotranspiration is 18 to 19 inches. Actual evapotranspiration is about 14 inches at this time. Thus, on a yearly basis, precipitation is approximately equal to actual evapotranspiration. However, the periods of maximum available moisture and maximum evapotranspiration do not coincide.

One would expect the ground to be thawed from the latter part of April through to the beginning of November as evidenced from the temperature data, and from discussions with farmers in the Vegreville area. If one considers the precipitation, evapotranspiration and time during which the ground is not frozen, it is evident that the most likely time that groundwater recharge reaches a maximum is in the latter part of April and May. Even then, most recharge may be expected to occur in the many small depressional areas within the dead-ice moraine where surface runoff rapidly collects.

Vegetation

The project area lies in the Parkland Prairie phytogeographic region (Moss, 1955). Originally aspen poplar (Populus tremuloides) was abundant in natural stands with balsam poplar (Populus balsamifera) being frequently present in moist lowlands (Rowe, 1959). The dominant native grass species was Festuca scabrella (Moss, 1955).

Today most of the area is cultivated. Only small areas of aspen poplar remain. Patches of willow (Salix spp.) and balsam poplar occur and are usually associated with moist conditions. Snowberry (Symphoricarpus occidentalis) and silverberry (Elaeagnus commutata) are sometimes present in small communities on local sandy chernozemic soils occurring within uncultivated areas of solonetzic soils. Other plants

including rose (Rosa sp.), saskatoon (Amelanchier alnifolia), and brome grass (Bromus inermis) often occur along fencelines, ditches, and in association with aspen. A number of phreatophytic and halophytic plant species are common in the area and will be discussed later.

Geology

Bedrock

The geology of an area has a direct influence upon the amount and quality of available groundwater. LeBreton (1963) summarized existing data on the geology of east-central Alberta and reported the bedrock formations relevant to this study. In ascending order of succession these are the Grizzly Bear, Birch Lake, and Pale and Variegated Beds members of the Belly River Formation. Areal extent of these members is shown on the contour map of the drift-bedrock contact (Map 1).

Surficial Deposits

The glacial features in the study area that are of considerable areal extent are undulating ground moraine and "dead-ice" moraine occurring in the west half and east half, respectively. Stream-trench systems make up a minor but significant portion of the area since all the permanent lakes which indicate discharge conditions are located here. A narrow band of alluvial deposits occur along the Vermilion River.

The areas of moraine consist of deposits of till, which is composed in part of poorly sorted as well as unsorted silt, clay, and a

few boulders, with lenses of sand and gravel. In the south-western portion of the study area and in the trenches sorted material sometimes overlies the till. The irregular extent and variable thickness of these sorted materials made separation from the till difficult at the map scale used. For this reason no attempt was made to delineate such shallow deposits and the soils were mapped as a complex.

IV. GROUNDWATER INVESTIGATIONS

Hydraulic Head Distribution

Methods

The main part of the groundwater survey consisted of sampling nearly all farm wells in the study area as well as adjacent areas within a two mile distance. At each well, water temperature, the depth of the well, and the depth to water were measured and recorded. However, where the water was pumped through a pressure system, temperature was not measured. Many of the wells could not be easily opened for viewing and the depths recorded are those indicated by the farmer.

The elevation (above mean sea level) of the non-pumping water level was determined for each well site from the estimated topographic elevations and reported depths to water. The well locations, water level contours predicted from the data, and surface topography are shown on a map (Map 2). Topographic contours shown in Map 2 were obtained from a map prepared for this project by the Technical Division of the Department of Lands and Forests, Edmonton.

Results and Discussion

Examination of the topography map (Map 2) suggests the following:

1. The water level is a subdued replica of the topography.
2. The depth to water level ranges from about 50 feet in the central topographically high region to about 10 feet in the topographically low areas. The water level is nearest the surface for a zone along the 2,100 foot elevation from the middle of Sec. 36, Tp. 52, R. 14 to

Sec. 24, Tp. 53, R. 13, and in all the stream trenches.

3. Since the direction of water movement is perpendicular to the lines of equal water elevation, assuming isotropic conditions, major water movement in this area is away from the central ridge. The direction of movement is most uniform along the west slope.

A number of important points arise from these results. Figure 7 shows the theoretical effect of groundwater movement on the average position of the water table. It may be observed that the depth to water table is greater at the higher elevation where groundwater recharge is predicted than at the lower elevation where groundwater discharge is predicted. Thus, on the basis of observed water levels (Map 2) one would expect major groundwater discharge to occur along the entire lower part of the west slope and in the stream trenches. The central ridge appears to be a major recharge area.

This is also supported by a comparison of water levels in shallow and deep wells in the recharge and discharge areas. In the predicted recharge areas the depth to water level increases as the depth of well increases. In the predicted discharge areas, the depth to water level remains nearly constant or increases slightly as the depth of well increases. This phenomena has also been observed and discussed elsewhere (Tóth, 1962).

Groundwater Chemistry

Methods

A total of 150 water samples from farm wells, springs, and the Vermilion River were collected in June, 1970, for chemical analysis.

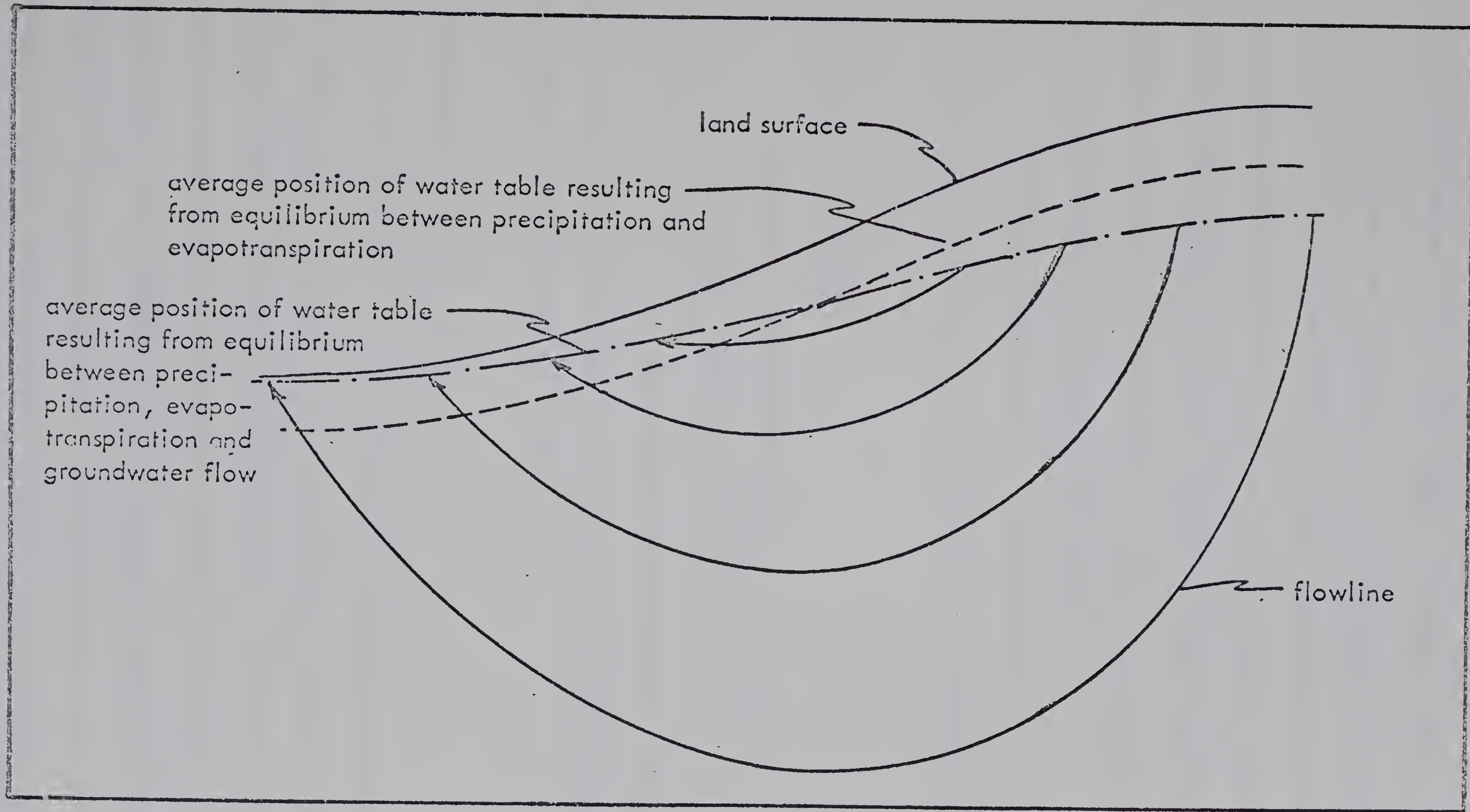


Figure 7. Diagrammatic representation of the average position of the water table as a result of groundwater flow (after Clissold, 1967).

Ions determined were Ca^{++}, Mg^{++}, Na^{+}, K^{+}, HCO_3^{-}, CO_3^{--}, SO_4^{--}, and Cl^{-}. Cl^{-} concentration was determined by potentiometric titration. Electrical conductivity and concentrations of other ions were determined according to the procedures used for analysis of soil extracts (page 59). pH was measured with a glass electrode pH meter. Total dissolved solids, expressed as equivalents per million (epm), was calculated from the sum of the concentrations of anions and cations.

The main objective of the analysis was to use groundwater chemistry as an aid for the interpretation of groundwater flow.

Results and Discussion

Results of the chemical analysis are presented in Appendix B and on a series of maps (Maps 3, 4, 5, and 6) showing contours of equal concentration for the various constituents determined analytically. Three accompanying hydrological profiles are included to show the vertical and lateral changes in water quality.

Total dissolved solids (TDS)

The content of dissolved solids increases with distance away from the central ridge and with increasing well depth at the higher elevations (Map 5 and Hydrological Profile). Groundwater recharge conditions are suggested within the central area bounded by the 30 epm contour line. The increase in TDS suggests groundwater discharge occurring within the stream trenches. Groundwater discharge is also evident along the entire lower portion of the west slope despite the lower content of TDS. The lower levels of TDS may result from a shorter time

of contact between water and flow media and/or from a difference in the chemical nature of soluble constituents within the flow media along the west slope as compared to that in the east half of the area.

Cation distribution

The preparation of contour maps depicting cation distribution patterns were limited to $Na^+ + K^+$ content since the relative concentrations of these cations increase along the groundwater flow path according to previous observations (Tóth, 1966a, b, 1968; Back, 1966). Five range classes were established to represent the relative concentrations of $Na^+ + K^+$ expressed as per cent epm. The areal extent of these is shown on Map 3. K^+ concentration is low and varies little in the study area so that Na^+ is the main indicator.

Examination of Map 3 suggests that groundwater recharge likely occurs within areas I and II and discharge likely occurs within area V, since the relative concentration of Na^+ increases along the groundwater flow path. Areas III and IV are transitional except along the stream trenches where narrow zones of area III are bounded by area II which indicates groundwater discharge conditions.

The accompanying hydrological profiles on the vertical axis show that at higher elevations where the Na^+ is not the dominant cation at least in the shallower wells an increase in $[Na^+]$[1] may be observed with increase in well depth. However, at the lower elevations Na^+ is usually dominant regardless of well depth. On the basis of these observations it may be concluded that the water is moving downward at the higher elevations and upward or laterally at the lower elevations.

[1] $[\ ]$ = concentration.

Anion distribution

Anion distributions were plotted for SO_4^{--} + Cl^- concentrations only since increases in relative concentrations of these anions closely reflect increases in flow length as observed earlier (Tóth, 1966a,b, 1968; Clissold, 1967). Five range classes, identical to those used to show cation distribution, were used to show the relative concentrations of SO_4^{--} + Cl^-. Cl^- concentration is comparatively low for most waters sampled, hence SO_4^{--} is the main indicator.

Map 4 shows the distribution of SO_4^{--} + Cl^-. It is apparent that individual anions are not good indicators of groundwater movement in this area. Theoretically, one would expect areas I and II to represent groundwater recharge conditions. In the study area, however, most of the west central low-lying region occurs in area II which was found to be mainly a discharge area according to all previous observations.

This discrepancy may be the result of one or more of the following:

1. a difference in chemistry of the geologic material,
2. a difference in time of flow, or
3. microbiological activity.

Areas IV and V which should indicate groundwater discharge reflect concentrations at individual wells rather than a general region. Possible explanations for these local conditions of high relative SO_4^{--} concentration are given later.

The presence of areas with low SO_4^{--} content is indeed important since this reflects the absence of regional groundwater discharge flow systems.

Calcium-magnesium ratio

The areal variation in the calcium-magnesium ratio is presented in Map 6. According to previous observations (Tóth, 1966a,b, 1968) the Ca:Mg ratio tends to be highest in the recharge area and lowest in the discharge area. On this basis, the areas on Map 6 with a ratio of 2.0 - 2.5 should represent groundwater recharge and those with a ratio of 1.0 - 1.5 should represent groundwater discharge. Obviously, the areas of recharge and discharge predicted by the Ca:Mg ratio do not match those predicted previously. However, the general trend that exists certainly supports previous observations.

A few anomalous values reported in the appendix were omitted from the map since they were related to very low concentrations of total Ca^{++} + Mg^{++} in the water samples and could be largely accounted for by the experimental error within the analytical procedure.

Summary

The results shown by the distribution of total dissolved solids, cations, anions, and Ca:Mg ratio indicate the following:

1. Individual cations and TDS are the best chemical indicators of groundwater flow in this area;
2. Major groundwater recharge occurs in the central topographically high region;
3. Major groundwater discharge occurs along the stream trenches, and along the lower portion of the west slope; and
4. Since low TDS and low relative concentrations of SO_4^{--} + Cl^- as

observed (Maps 3, 4) were previously found (Tóth, 1966a,b, 1968) to be related to local and intermediate rather than regional groundwater flow systems, it is very likely that only local and intermediate flow systems exist in the study area.

Unusually high TDS contents and SO_4^{--} concentrations were observed at a few individual well sites mostly in the southwest portion of the study area and give values which were completely anomalous for the area. These may result from one or more of the following:

1. Contamination of water in farm wells following seismic blasting and drilling of natural gas wells.

   At well sites, numbers 2 and 65 (Map 2), the farmers reported that the water quality in the wells deteriorated, about 15 years ago, shortly after a gas well was drilled within 3/4 of a mile of the farm wells. The chemical analysis of the water from the farm wells shows that at site 2 the amount of TDS and relative SO_4^{--} concentration are much higher than expected but at site 65 the chemical constituents are comparable to those of the area.

2. Seepage of natural gas into the farm water wells.

   Farmers reported natural gas seepage into the water wells at site 117 and near site 1. At site 117 the water quality corresponds to predicted values. The well near site 1 was 360 feet deep but is now sealed. An analysis obtained from the farmer, as determined by the Provincial Analyst, indicated very high TDS (7,782 ppm), but not a relative high SO_4^{--} content.

3. Location and depth of the well being such that water is derived from a stagnant zone between two flow systems.

The latter is perhaps the most logical explanation.[1] It could explain the anomalous values discussed above. As well, it is supported by comparison of adjacent well locations which are shown on Map 2 and hydrochemical analysis presented in Appendix B. At site 7 the well is 60 feet deep, high in TDS and high in relative SO_4^{--} concentration whereas at site 8 the well is 240 feet deep, low in TDS and has no SO_4^{--}. The reverse situation exists at sites 63 and 64; the shallow well has low TDS and no SO_4^{--}, the deep well has high TDS and high relative SO_4^{--} concentration. These observations indicate that the stagnant zone may be relatively shallow or deep.

The distribution of other constituents in the TDS provide a logical explanation for the occurrence of the relatively low sulfate content in the discharge region of the western section of the study area.

The chemistry and permeability of the geologic material may be important since examination of the bedrock and surface topography shows that the till is slightly thicker in the east half of the area. Since Ca^{++}, Mg^{++}, and SO_4^{--} are generally regarded as being derived mainly from till, the occurrence of higher relative and absolute amounts of these ions are predictable along the east side of the area. Na^+ is mainly derived from the bedrock and may be expected to dominate along the west side where a longer portion of the flow path passes through the bedrock. The absolute amount of $CO_3^{--} + HCO_3^-$ found in TDS remains comparatively uniform throughout the area. Therefore, on the basis of the foregoing, low sulfate content in the water samples from wells and

[1] Personal communication with Dr. Tóth.

springs along the western portion of the study area probably results from relatively lower concentrations of sulfate in the bedrock as compared to till.

Another possible phenomena which may explain the low sulfate content along the lower west slope is microbial reduction. The microbiological analysis of the spring water and mud samples (Appendix D) shows very high numbers of facultative sulfate reducers. Since these organisms are capable of surviving at depth in relatively high numbers,[1] they could at least in part, contribute significantly to decreasing the sulfate concentration. High pH found in water samples from this area is further evidence for biogeochemical reduction. While such processes are very possible,[1] a microbial examination of water samples from a deep well is required before this phenomena can be fully confirmed.

Surficial Features of Groundwater Flow

Methods

A mapping of surficial groundwater features was conducted in August, 1970. The features recognized were:

1. springs
2. seepages
3. flowing wells
4. natural vegetation
5. salt precipitates
6. burnt crops

[1] Personal communication with Dr. Cook, Professor, Department of Soil Science.

7. soapholes
8. moist depressions
9. dry depressions
10. man-made objects and local reports.

There were two main objectives of this survey: (1) to establish criteria for the classification of moist depressions into four categories based in part on the system presented by Tóth (1966a) and in part on the observable features in the study area; and (2) to use the features listed above as they are used in Tóth's classification (Tóth, 1966a) to interpret and outline areas of upward and downward moving groundwater without reference to pedogenic indicators.

According to Tóth (1966a), moist depressions may be distinguished as high-land type and low-land type. In order to facilitate the present investigations it was decided to further develop criteria for separation of moist depressions into four categories based on ecological observations within the study area.

A number of depressional areas were investigated and described according to vegetative composition, vegetative patterns, and permanence of water. On the basis of these investigations, the moist depressions were separated into four categories, namely, (1) fast recharge; (2) slow recharge; (3) discharge; and (4) indefinite. The presence or absence of salt precipitates at each depression was noted but not used as a criterion since this would tend to bias the related soil studies.

After establishment of criteria for differentiating the sloughs into the four categories, a systematic classification of sloughs was conducted along traverses through the area resulting in approximately 90 separate investigations. Traverses were plotted on aerial photographs

and were designed to provide complete randomized coverage of the area.

All locations of soapholes, springs, seepages, etc., recognized in the map area were recorded (Map 7) and described in Appendix C.

Results and Discussion

Springs

Seven springs were found within the study area, six of which have estimated flow rates of less than one gallon per minute (gpm) and freeze during the winter. These six all occur along the lower portion of the west slope. The spring at site 80 (Map 7) has an estimated flow rate of 3 gpm and is perennial. It occurs on the bank of a stream trench. Recognizable gullies have formed at most of the spring sites probably as a result of erosion enhanced by the discharging water (Plate I). Local farmers reported that springs were present at the base of the Vermilion River at two sites within the study area.

Seepages

Several seepages occur along the lower west slope of the area and are usually associated with a specific type of erosional feature (Plate II). Generally, the topsoil is differentially eroded away leaving a hummocky micro-relief pattern. Salt precipitates and red samphire (*Salicornia rubra*) are present on the lower eroded surfaces whereas the elevated, non-eroded surfaces are characterized by comparatively dense

Plate I. Large gully formed at spring site. Notice phreatophytes on foreground and salt precipitates.

Plate II. Hummocky micro-relief associated with seepages. Halophytes, phreatophytes and salt precipitates also present.

vegetation comprised of a wide variety of plant species. Baltic rush (Juncus balticus) often grows at the upslope edge of the eroded surfaces where seepage waters are constantly discharging.

Natural vegetation

The species of natural vegetation commonly associated with groundwater features and used in mapping are outlined in Table 5. The vegetation characteristic of recharge conditions is confined to moist depressions while that characteristic of discharge conditions may be found near springs and seepages as well.

Salt precipitates

It is valid to consider salt precipitates as indicators of groundwater discharge apart from their direct relationship to soil classification. The whitish salt crusts form at the soil surface as a result of evaporation of shallow groundwater containing high amounts of TDS. Chemical analysis of saturated extracts from solonetzic and saline regosolic soils from the study area suggest that the dominant salt in the precipitates is Na_2SO_4.

Salt precipitates are particularly useful for mapping purposes because they are easily recognized on aerial photographs and are easily spotted in the field (Plates III and IV).

The precipitates occur throughout the groundwater discharge area; along margins of drainage ways; around moist depressions; in dry depressional areas; and as spots near the break in slope below the midline of the west slope. In addition, they are associated with other

Table 5. Vegetation Associated with Recharge and Discharge Features*

Vegetation associated with recharge sloughs:

Cattail	Typha latifolia
Creeping spike rush	Eleocharis palustris
Water parsnip	Sium suave
Tall manna grass	Glyceria grandis
Northern manna grass	Glyceria borealis
Water persicaria	Polygonum natans
Slough grass	Beckmannia syzigachne
Awned sedge	Carex atherodes
Beaked sedge	Carex rostrata
Willow	Salix spp.
Western water horehound	Lycopus asper
Marsh hedge nettle	Stachys palustris
Hemp nettle	Galeopsis tetrahit

Vegetation associated with discharge features:

Aquatic plants (undifferentiated)	
Great bulrush	Scirpus validus
Prairie bulrush	Scirpus paludosus
Three-square bulrush	Scirpus americanus
Cattail	Typha latifolia
Baltic rush	Juncus balticus
Creeping spike rush	Eleocharis palustris
Narrow reed grass	Calamagrostis neglecta
Tall manna grass	Glyceria grandis
Awned sedge	Carex atherodes
Beaked sedge	Carex rostrata
Slough grass	Beckmannia syzigachne
Western dock	Rumex occidentalis
Tuberous rooted sunflower	Helianthus subtuberosus
Tufted hair grass	Deschampsia caespitosa
Nuttall's salt meadow grass	Puccinellia nuttalliana
Foxtail	Hordeum jubatum
Gumweed	Grindelia perennis
Red samphire	Salicornia rubra

* Common and scientific nomenclature after Budd and Best (1964).

Plate III. Salt precipitates in marsh. Large whitish area at center occurs at the break in slope.

Plate IV. Salt precipitates on cultivated field.

discharge features such as springs, seepages, and soapholes. Salt precipitates were not found anywhere in the central upland region despite a careful search.

Burnt crops

Burnt crops, like salt precipitates, indicate the presence of shallow groundwater with high amounts of TDS. Grain crops such as wheat, barley, and oats are adversely affected by the presence of excessive amounts of sodium sulfate. "In the early stage of development, crops are retarded in their growth in the affected areas; later they are conspicuous from their unhealthy yellowish color in the otherwise green fields (hence the name 'burnt' crops) and by the nonuniform, sparse pattern of growth. Still later the affected areas become nearly barren, with individual stalks being short and heads poorly developed." (Tóth, 1966a, p. 60).

The value of burnt crops as indicators of groundwater discharge increases when salt precipitates and seepages are masked by precipitation.

Soapholes

Soapholes observed in the study area are of the small-mound type (Clissold, 1967). A typical soaphole (site 5,Map 7) is illustrated in Plate V.

All the soapholes observed in the study area occur just below the break in slope, below the midline of the west slope. They are usually found near seepages.

Plate V. Soaphole with associated phreatophytes and salt precipitates.

Plate VI. A cultivated fast recharge slough. Notice uniform crop growth near slough and lack of salt precipitates.

Moist depressions

On the basis of field observations, four main types of moist depressions were used for the categorization of sloughs in the map areas and were distinguished according to the following criteria:

(a) Fast recharge. Surface water recedes rapidly and usually disappears by fall in these sloughs. The most readily observable vegetation usually consists of a central zone of water parsnip and tall manna grass grading into a zone of awned sedge which is surrounded by a ring of willows. Sometimes these depressions are cultivated. However, when they are too wet for planting in spring, slough grass becomes the dominant vegetation during the summer (Plate VI). Nowhere are there salt precipitates or halophytic plants associated with these sloughs. These sloughs are the most common type of the central topographically high region. Their presence suggests rapid downward movement of meteoric water, hence the name fast recharge.

(b) Slow recharge. These sloughs also lack salt precipitates and halophytic vegetation but they usually remain wet throughout the year. Typically, cattail, creeping spike rush, awned sedge, and willow occur in respective order away from the center of the slough (Plate VII). As in fast recharge sloughs, there is a rapid transition from the central wet zone to the adjacent dryland. Slow recharge sloughs are abundant in the east half of the study area below the central ridge but some distance upslope from the stream trenches. The slow recharge sloughs indicate a lower potential for groundwater recharge in comparison to the fast recharge sloughs. Electrical conductivity for both types of recharge sloughs was measured to be less than 0.75 mmhos/cm.

Plate VII. A slow recharge slough. It occurs in the intermediate discharge area as an "island" phenomena.

Plate VIII. A discharge slough. Notice concentric zones of vegetation, permanent water, and salt precipitates.

(c) Discharge slough. Three features are obvious at first sight of these sloughs -- permanent surface water, halophytic and phreatophytic vegetation, and salt precipitates (Plate VIII). A number of concentric zones of vegetation reflect a gradual change in water quantity away from the center of the depression.

Submerged aquatic plants which were not identified may be found in the deep water zone. Bulrushes, such as great bulrush, prairie bulrush, and three-square bulrush, usually make up the vegetative zone adjacent to the open water. The next zone in which the plants are still partly submerged, may consist of baltic rush and creeping spike rush. Tall manna grass and awned sedge often occur at the transition zone from submerged to permanently saturated soil conditions. Nuttall's salt meadow grass, foxtail, and gumweed are the dominant vegetative species existing on the comparatively dry saline soils near the depressions. Local patches of red samphire may also be found in this zone. Willows are absent. The electrical conductivity of water in discharge sloughs is usually greater than 1 mmhos/cm.

The above features may be found associated with all lakes located in the stream trenches as well as with a few depressions occurring in the lower portion of the west slope of the study area.

(d) Indefinite slough. These depressions are characterized by features indicating both upward and downward moving water. For example, there may be halophytic and phreatophytic species in a few distinguishable zones of vegetation suggesting discharge conditions and, on the other hand, an obviously receding water level and a few willows. On the basis of these features it was impossible to decide

whether such sloughs were recharge or discharge. They are generally located between areas of groundwater recharge and groundwater discharge.

Dry depressions

These depressions are similar in size and shape to the previously described "moist depressions" but lack the characteristic features associated with the wet conditions of the latter. Both native species and planted crops growing in these depressions appear the same as on adjacent fields. "Two factors are thought to be responsible for the dryness of these depressions: (1) good permeability of the soils and of the underlying formation allowing quick infiltration of rainwater; and (2) a position relative to groundwater flow-systems that prevents the depression from receiving any contribution from groundwater." (Tóth, 1966a, p. 63). It may be assumed that the permeability of soils in the study area is more or less uniform throughout. The second condition is satisfied in areas of downward flow of groundwater, and is supported by field observations. All the dry depressions found in the study area occur at relatively high elevations.

Man-made objects and local reports

Man-made objects observed in the study area that are useful indicators of groundwater discharge include a flowing well and fences around soapholes.

Local reports indicate that groundwater flow from many of the springs, seepages, and soapholes was greater at least 40 years ago than

at present. The present drier conditions may be the result of a change in climate or the effect of cultivation in the area.

Summary

Results obtained from the mapping of surficial groundwater features indicate that: (1) most groundwater recharge features occur in the central upland region; (2) most groundwater discharge features occur in the stream trenches and within a band about 1/2 mile wide below the midline of the west slope; (3) there is a narrow transitional zone between the recharge and discharge areas that is characterized by indefinite features; (4) both groundwater discharge and groundwater recharge features, the former being more abundant, occur in the zone between the "band" described in (3) and the Vermilion River; and (5) both groundwater discharge and groundwater recharge features, the latter being more abundant, occur along the south-central portion of the study area.

Conclusion of Groundwater Investigations

On the basis of information obtained from the hydraulic head, distribution, groundwater chemistry, and surficial groundwater features, a map was prepared to show major areas that represent different conditions with regard to groundwater movement. A total of five areas were differentiated and are shown on Map 8. The distinguishing characteristics of each area are described below and the generalized vertical flow paths are illustrated in Figures 8 and 9.

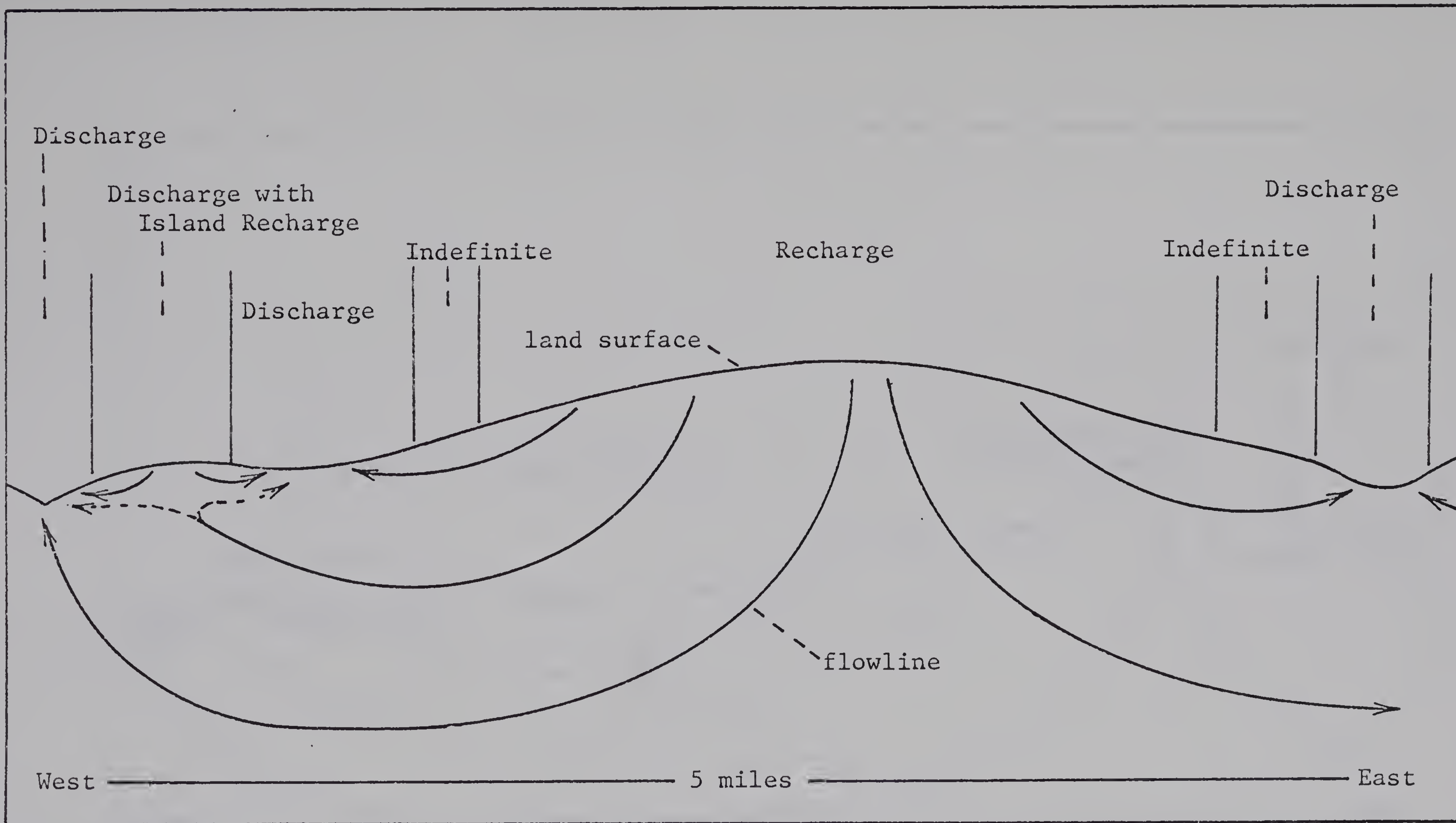


Figure 8. Predicted Groundwater Flow Paths and Associated Recharge and Discharge Areas. This is a Cross-section through the Central Part of the Study Area.

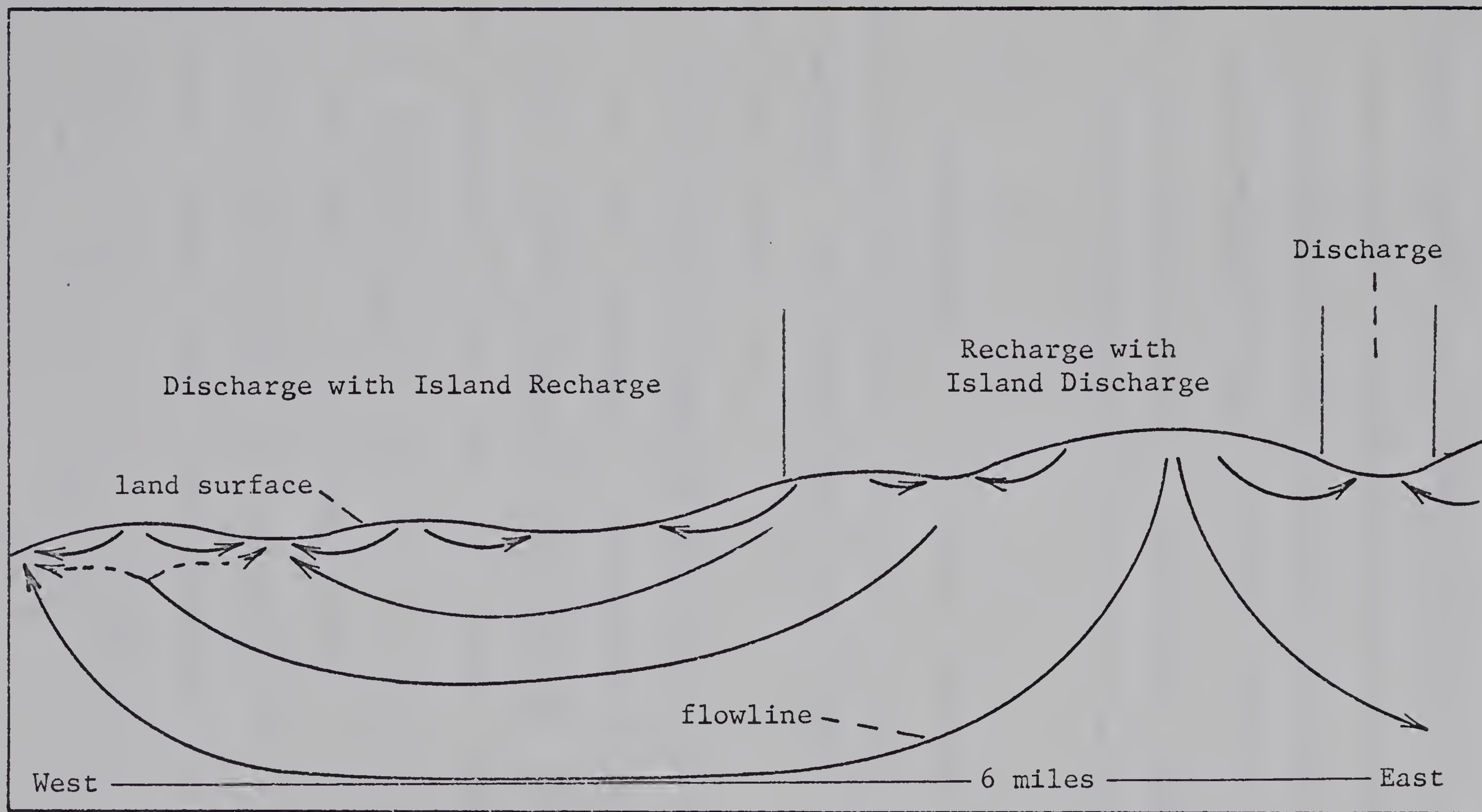


Figure 9. Predicted Groundwater Flow Paths Illustrating "Island" Phenomena. This is a Cross-section through the Southern Part of the Study Area.

(a) Recharge area. All phenomena observed within this area either indicate or may be interpreted to indicate groundwater recharge. This is mainly the recharge area for the intermediate flow systems.

The water table is comparatively deep and the depth to the water level in wells increases with increasing well depth. Chemically, the waters contain mainly Ca^{++}, Mg^{++}, and HCO_3^- and have low TDS. Dry depressions, fast recharge sloughs and slow recharge sloughs are present. No springs, seepages, salt precipitates, and halophytic vegetation occur.

(b) Discharge area. All groundwater phenomena observed within this area indicate or may be interpreted to indicate groundwater discharge conditions. This is apparently the discharge area for the intermediate flow systems.

The water table is comparatively shallow. Na^+ and HCO_3^- are the dominant ions which constitute the relatively high TDS. The observed surficial features include discharge sloughs, springs, seepages, soap-holes, salt precipitates, burnt crops, and halophytic vegetation.

(c) Indefinite area. This area is of limited extent; consequently, a small number of water levels, chemical analysis, and surficial features were observed. The indefinite area is probably the midline and upper discharge area of the intermediate flow system. The phenomena observed integrate between those suggesting recharge and discharge. For example, indefinite sloughs, and intermittent seepages may be found in this area.

(d) Discharge with island recharge. The groundwater phenomena observed throughout a major portion of this area indicate groundwater discharge conditions. Discharge sloughs, salt precipitates, burnt crops, and halophytic vegetation commonly occur but no springs or soapholes were observed in this area. Water chemistry is comparable to that in the discharge area described in (b), except for a few isolated anomalous values that occur.

In addition to the discharge features, there are localized recharge features. These include mainly fast recharge sloughs which usually occur on slightly elevated landscape positions.

The presence of both recharge and discharge features in this area may be expected. The whole area is part of the discharge area of the intermediate flow system but superimposed on it are local flow systems. The latter develop due to the influence of local topography in this area which may be characterized as an undulating till plain with considerable local relief. As a result, there are spots or "islands" of recharge within the local flow systems.

The discharge features form as a result of discharge from both local and intermediate flow systems. However, since the flow paths of the local flow systems are generally short, the water quality does not change markedly and the discharge features, such as salt precipitates and burnt crops, resemble those of the intermediate discharge area.

Since there are no springs or soapholes in this area it may be expected that the intermediate discharge potential is not as great as in the discharge area as observed at (b).

The presence of local anomalous values as observed for sites 2, 7, and 63 (Map 2) also supports the presence of local flow systems superimposed on intermediate flow systems since the "pockets" between flow systems are stagnant and the water accumulates high SO_4^{--} concentrations and high TDS.

(e) Recharge with island discharge. Features in this area generally represent groundwater recharge conditions, however, a few "islands" of discharge occur.

Water levels in wells are somewhat shallower in this area than in the recharge area in (a). Water samples from shallow wells (approximately 50 ft. deep) in this area usually contain mainly Ca^{++} and HCO_3^- whereas deeper wells (approximately 100 ft. deep) have mainly Na^+ and HCO_3^-. Sloughs are mostly of the fast and slow recharge types but a few indefinite and discharge sloughs occur. These two latter types may be both recharge and discharge at different times during the year as discussed by Meyboom (1967a) or they may be transitional as described by Lissey (1968). No springs, seepages, soapholes, or anomalous values of water chemistry occur in this area.

This appears to be an intermediate recharge area; however, the potential for recharge is not too great. Local flow systems are superimposed on the intermediate recharge area which results in the formation of islands of discharge from the local flow systems. Waters in these local flow systems contain mainly Ca^{++} and HCO_3^- and do not contain appreciable amounts of Na^+ and SO_4^{--}. As a result, salt precipitates that form in the local discharge areas consist mainly of carbonates rather than sulfates.

V. SOIL INVESTIGATIONS

Soil Development

Five main factors which influence soil development are climate, living organisms, parent material, topography, and time. The effects of climate, living organisms, and time may be assumed to be the same throughout the present study area and, therefore, should not cause major variations in soil development.

The parent material of the area is generally similar in lithology and is primarily of glacial drift origin. Thus, the more readily soluble salts were likely originally of similar concentration and distribution throughout. Subsequent changes in salt distribution throughout the parent material likely had a profound influence on pedogenesis.

Topography appears to be the major controlling factor governing local and regional soil development as well as groundwater movement in the study area. Hence, field mapping of the soils is essential to determine whether there is any relationship between soils and groundwater distribution in the study area.

Soil Survey and Mapping

Methods

A detailed soil survey was conducted on the study area during the summer of 1969. The soil profiles along traverses comprising a

total of 50 to 100 sites per section of land were examined to an average depth of 40 inches and classified according to the Canadian Soil Classification System (N.S.S.C., 1968).

An aerial photographic mosaic was used as a basis for field mapping, at a scale of 6 inches = 1 mile. The final soil map (Map 9) was prepared at a scale of 3 1/2 inches = 1 mile.

The mapping units used in the study area define the soil subgroup, parent material, and topographic classes, either individually or as complexes. The soil individuals are listed in order of decreasing areal extent and generally those that represent less than 10 per cent of a particular area are not included in the map unit. The type of parent material is designated by a solid, dashed, or dotted line for till, till and sorted material, or alluvial material, respectively. Topographic classes included in the soil edits are not used as criteria for delineating soil boundaries.

Some representative soil individuals were sampled and analyzed for physical and chemical characterization.

The following analytical procedures were used:

<u>Soil Reaction</u>: Soil paste method as outlined by Doughty (1941) using a glass electrode pH meter.

<u>Total Nitrogen</u>: Kjeldahl method by Jackson (1958), using a mixture of HgO, $CuSO_4$, and K_2SO_4 (Kel-pak) as catalyst.

<u>Total Carbon</u>: Dry combustion procedure using an induction furnace as outlined by Allison (1965). The CO_2 evolved was determined gasometrically with a Leco Model 577-100 carbon analyzer.

$CaCO_3$ Equivalent: A Smolik calcimeter (Bascomb, 1961) was used.

Exchange Acidity: This was determined according to the procedure by Brown (1943).

Exchangeable Cations and Exchange Capacity: The procedures outlined in A.O.A.C. (1955) were used. A Perkin Elmer 303 Atomic Absorption Spectrophotometer was used to determine the cations (Ca^{++}, Mg^{++}, Na^+, K^+).

Soluble Salts: The saturation extract was obtained by suction from a saturated paste as outlined in U.S.D.A. Handbook 60 (1954). Ca^{++}, Mg^{++}, Na^+, and K^+ were determined with a Perkin Elmer 303 Atomic Absorption Spectrophotometer. Sulphate was determined by the turbidimetric method used in the Alberta Soil Survey Laboratory.

Electrical Conductivity: A direct reading Solu-Bridge Model RD-26 was used to measure the conductivity of the saturation extracts.

Particle Size Analysis: The pipette method (Toogood and Peters, 1953) was used.

Bulk Density: A soil coring device mounted on a 1/2 ton truck was used. Cores of individual horizons were obtained by forcing a 1 3/4 inch diameter steel corer vertically through the soil profile.

Hygroscopic Moisture: Air dried samples were oven dried overnight at 105°C.

Results and Discussion

General

Soils of the Chernozemic, Solonetzic, Gleysolic, and Regosolic Orders, in respective order of decreasing areal extent, were mapped in the study area. The soils are developed on parent materials categorized into three types; namely, till, till and sorted material, and alluvium. The texture of the surface soil horizon is loam for most of the study area. Small areas of sandy loam occur particularly in areas of sorted material and alluvium but these were not mapped individually. The soil map (Map 9) shows the distribution of the soils, parent materials, and topographic classes.

Profile descriptions and results of physical and chemical analysis for 14 soil profiles, not all of which represent different subgroups, are presented in Appendix A-I. The typical horizon sequences for all the subgroups are presented in Appendix A-II.

Soil Classification

A. Chernozemic Order

Chernozemic soils consist of well to imperfectly drained soils developed under grassland or transition grassland-forest and are characterized by a prominent dark colored surface horizon. The underlying B or C horizons have high base saturation with divalent cations, calcium usually being dominant.

Black Great Group

These soils have very dark gray or black[1] Ah horizons which are not less than 3.5 inches thick. In soils disturbed by cultivation the Ap horizon must be at least 6 inches thick and meet the above color criteria.

Eluviated Black Subgroups. The Eluviated Black Subgroup is the dominant soil mapped in the study area. Generally, it has a black Ah[2] horizon which is 10 to 14 inches thick; a dark brown Ahe horizon that is weakly developed; a dark yellowish brown Bt horizon; a transitional BC horizon; and a dark grayish brown Cca horizon, in descending order. The lime accumulation horizon (Cca) usually begins at a depth of 30 to 40 inches and is about 10 to 20 inches thick. An Eluviated Black profile in which the Ahe has been destroyed as a result of cultivation is shown in Plate IX.

Chemical analyses show that Ca^{++} followed by Mg^{++} are the dominant exchangeable and soluble cations throughout the profile. HCO_3^- is the dominant soluble anion but small amounts of SO_4^{--} may be present in the C horizon. Electrical conductivity is generally less than 1 mmho/cm in all horizons.

Morphological descriptions and chemical analyses for two Eluviated Black profiles are given in Appendix A-I.

The Truncated Eluviated Black is characterized by a comparatively thin (less than 6 inches) Ap horizon which reflects the effect of surface erosion. Otherwise, it is similar to the Eluviated Black soils.

[1] Munsell soil color names.

[2] Upper 6 inches of the Ah is often an Ap horizon.

Ap

Bt1

Bt2

BC

Cca

Plate IX. Cultivated Eluviated Black profile. This soil occurs in the groundwater recharge area.

Ah

Ae

Bnt

Ccasa

Plate X. Thin Black Solonetz -- an indicator of groundwater discharge. Note the dark stained Bnt horizon and the salt blotches in the Ccasa.

The Carbonated Eluviated Black differs from the Eluviated Black in that the former has secondary carbonates and colors of slightly lower chroma in the B horizon.

The Gleyed Eluviated Black has mottles in the B and C horizons. A complete description of this soil is given in Appendix A-I.

Truncated Eluviated Black and Eluviated Black soils usually occur on well drained sites; the Carbonated and Gleyed subgroups are found on imperfectly drained sites.

A Saline Eluviated Black soil was sampled and a complete description of it is presented in Appendix A-I. Morphologically this soil resembles the Eluviated Black, however, chemically it differs. $(Na^{+}) > (Mg^{++}) > (Ca^{++})$ and $(SO_4^{--}) > (HCO_3^{-})$ in the C horizon of the Saline Eluviated Black. However, this soil was not mapped in the study area because it did not occur extensively.

Rego Black Subgroup. The Rego Black subgroup has Ap and/or Ah horizons, about 12 inches thick, underlain by transitional AC and Cca horizons. This soil generally occurs on imperfectly drained sites near depressions and below the midline of the west slope in the study area.

The A horizons may be infused with secondary carbonates and/or salts that have precipitated from solution to form Carbonated and/or Saline Rego Black Chernozem, respectively. In addition, these soils may be gleyed.

An unusually thick A horizon (about 40 inches) is the main characteristic of the Cumulic Rego Black soil. A description of this soil is given in Appendix A-I. The Cumulic Rego Black soil individual

often occurs in snowberry (<u>Symphoricarpus occidentalis</u>) patches within the area of solonetzic soils. It is developed on sandy parent material. Ca^{++} is the dominant soluble and exchangeable cation.

<u>Solodic Black Subgroup</u>. These soils have very dark gray Ah or Ap horizons about 8 inches thick, underlain by a sequence of Ahe, Ae, and transitional AB horizons, overlying a prismatic or blocky structured Bnjt horizon with pronounced coatings. The Cca and Ccasa horizons occur at approximate depths of 30 and 40 inches, respectively.

The Solodic Black profiles occur as integrades between Eluviated Black and Black Solod profiles. No large areas of Solodic Black soils have been delineated in the study area.

B. <u>Solonetzic Order</u>

The following quotation from the Canadian Soil Classification System (C. D. A., 1970, p. 64) summarizes the main characteristics of the solonetzic soils observed in the study area. "These soils have solonetzic B and saline C horizons. Morphologically a solonetzic B horizon is characterized by a columnar or prismatic macrostructure that can be broken into a blocky mesostructure. The blocks are hard to very hard in consistence when dry and have dark surface stains. Chemically the solonetzic B horizon has a ratio of exchangeable Ca to exchangeable Na of 10 or less. They are well to imperfectly drained soils."

Solonetz Great Group

In soils of this Great Group there is an abrupt break between the A and B horizons. The Bnt is very hard columnar and the upper part of the columns remain intact when removed from the soil. The round tops usually have a thin capping of white siliceous material. There are very dark gray to black stains on the ped surfaces.

Black Solonetz Subgroups. The soils mapped as Black Solonetz in the study area have very dark gray to black Ah horizons that are usually 6 to 8 inches thick and must be more than 4 inches thick. They have Bnt horizons, approximately 6 to 10 inches thick, overlying saline, calcareous C horizons. Descriptions and analyses for 2 profiles sampled in the study area are given in Appendix A-I.

The dominant soluble salt in the B and C horizons is Na_2SO_4. Mg^{++} is present in slightly higher concentrations than Ca^{++} in the soluble salt extracts. Cation exchange analysis indicates that Ca^{++} is dominant in the Ap horizon but Na^{+} or Mg^{++} is dominant in the Bnt horizon. Electrical conductivity ranges from 5 to 14 mmhos/cm in the B and C horizons.

The Black Solonetz soils are most common along the lower portion of the west slope in the study area where they have been delineated as individual map units and in complexes usually with Thin Black Solonetz or Eluviated Black soils.

Carbonated Black Solonetz soils are characterized by the presence of secondary carbonates in the B and in some instances in the A horizons.

Gleyed Black Solonetz soils mapped in the area have some mottling and colors of lower chroma in the A, B, and/or C horizons.

Carbonated and Gleyed Black Solonetz soils are generally found in low-lying regions within the areas of Black Solonetz soils.

Thin Black Solonetz Subgroups. The Thin Black Solonetz soils mapped in the study area have Ah horizons that are not more than 4 inches thick. This was the major criterion used to distinguish these soils from the Black Solonetz. A Bnt horizon, approximately 6 inches thick, and a saline, calcareous C horizon underlie the A horizon. Descriptions and analyses for 3 Thin Black Solonetz soils are presented in Appendix A-I. A picture of a Thin Black Solonetz is illustrated in Plate X.

Chemically, the Thin Black Solonetz are similar to the Black Solonetz soils. Analysis of soluble extracts show that Ca^{++} is dominant in the A horizon and Na^{+} is dominant in the B and C horizons. SO_4^{--} is the dominant anion in all the horizons of the Thin Black Solonetz soils. Electrical conductivity is comparable to that in the Black Solonetz soils.

These soils generally occur within a band about 1/2 mile wide below the midline of the west slope as shown on the soil map (Map 9). They are associated with the Black Solonetz soils which occur on the slightly elevated landscape positions and Saline Carbonated Gleysols which occupy depressional areas.

Carbonated and Gleyed Thin Black Solonetz soils were also mapped, mostly near depressions, and are relatively more abundant than Carbonated and Gleyed Black Solonetz soils.

Solod Great Group

These soils have a distinct AB transition horizon and a Bnt horizon in which the upper portion breaks readily into blocky aggregates. There is no well defined break between the AB and Bnt horizons.

Black Solod Subgroup. The Black Solod soils that occur in the study area have very dark gray to black Ah or Ap horizons, about 8 inches thick, underlain by a sequence of Ae, AB, Bnt, and Ccas horizons. A complete description of a Black Solod profile is given in Appendix A-I.

In the Black Solods, Ca^{++} is the dominant exchangeable cation in the A and B horizons. However, Na^{+} is the dominant cation in the soluble extracts of the B and C horizons. Electrical conductivity is less than 1 in all horizons above the Ccasa.

These soils are not extensive in the study area. They occur most commonly as integrades between small areas of chernozems, such as those occurring in snowberry (S. occidentalis) patches, and solonetzic soils.

C. Gleysolic Order

These soils are saturated with water and are under reducing conditions continuously or during some significant period of the year. Consequently, they have matrix colors of low chroma within 20 inches of the mineral surface and they may have mottles of high chroma. Gleysolic soils generally occur in undrained depressions and support hydrophytic vegetation.

Humic Gleysol Great Group

These are gleysolic soils that, when virgin, have black Ah horizons more than 3 inches thick, and commonly about 8 inches thick in the study area.

Orthic Humic Gleysol Subgroups. The Orthic Humic Gleysol soils have a noneffervescent Ah horizon, a gleyed B horizon, and a strongly gleyed C horizon. They generally occur in fairly wet depressions at moderately high elevations in the study area.

The Saline and/or Carbonated Orthic Humic Gleysols are recognized in the field by the presence of salts and/or lime, respectively, in the A and B horizons. These soils are found in wet depressions which occur at relatively low elevations within the study area.

Rego Humic Gleysol Subgroups. Rego Humic Gleysol soils have noneffervescent Ah horizons underlain by gleyed C horizons.

The Saline Rego Humic Gleysol has a saline A horizon and generally occurs downslope from and adjacent to the Saline Orthic Humic Gleysol.

Similarly, the Carbonated Rego Humic Gleysol has secondary carbonates in the A horizon and often occurs downslope from and adjacent to the Carbonated Orthic Humic Gleysol.

Saline Carbonated Rego Humic Gleysols are of common occurrence and likewise are associated with Saline Carbonated Orthic Humic Gleysols.

Eluviated Gleysol Great Group

These are Gleysolic soils with well developed Aeg and Btg horizons. They are found in rapidly drying depressions and are often cultivated.

Humic Eluviated Gleysol Subgroup. These are eluviated Gleysol soils with very dark grayish brown Ah and Ahe horizons that have a combined thickness of approximately 6 inches. The platy, grayish brown Aeg horizons vary from 2 to 5 inches in thickness. The Btg horizons are mottled and have dark gray to gray matrix colors. Lime is seldom present in the Cg horizon.

Chemical analyses show that Ca^{++} is the dominant exchangeable cation. A complete description of this soil is given in Appendix A-I and is illustrated on Plate XI.

Ah
Ahe
Aeg
Btg
BCg
Cg

Plate XI. Humic Eluviated Gleysol. There are no saline or carbonated horizons in this soil. It is located in a fast recharge slough.

Low Humic Eluviated Gleysol Subgroup. These soils are essentially identical to the Humic Eluviated Gleysols except that the Low Humic Eluviated Gleysols have Ap horizons that are grayer than those of the latter.

The Low Humic Eluviated Gleysol soils are not common in the study area and occur only in some cultivated depressions.

D. Regosolic Order

Regosol soils mapped in the study area are imperfectly drained mineral soils having horizon development too weak to meet the requirements of soils in any other Order. The definition for the Regosol Great Group is the same as that for the Order.

Regosol Subgroups. Two types of Regosols were recognized and mapped in the study area. Complete descriptions and analysis for both types are presented in Appendix A-I.

The Saline Carbonated Regosol has a grayish brown, moderately saline, and weakly effervescent surface horizon that is about 3 inches thick. This is underlain by a strongly saline, moderately effervescent dark grayish brown horizon that is about 8 inches thick. The upper part of this horizon vaguely resembles a Bnt of a Thin Black Solonetz and the lower part is amorphous in structure. Saline and calcareous parent material underlies the above horizons.

Na^+ is the dominant cation in the saturated extracts of all the horizons. Its concentration ranges from 100 to 400 meq/1 as compared

to the concentration of Ca^{++} + Mg^{++} which does not exceed 5 meq/l. In all horizons, SO_4^{--} concentration is high and HCO_3^- concentration is higher than that in any other profile sampled in the study area.

The Saline Carbonated Gleyed Regosol soils have strongly saline, moderately effervescent, very dark gray A horizons that may be up to 10 inches thick underlain by lime and salt accumulation horizons which are usually about 15 inches thick. This latter horizon is dark gray in most instances. However, at some sites, such as the one described (Appendix A-I), it has yellowish brown color which may indicate the presence of relatively well oxidized water and precipitation of iron oxides.

Chemical analysis of saturated extracts (Appendix A-I) indicate that $(Na^+) > (Mg^{++}) > (Ca^{++})$ and $(SO_4^{--}) > (HCO_3^-)$ in all horizons. Electrical conductivity is > 20 mmhos/cm in the A and Ccasag horizons.

The Carbonated Saline and Carbonated Saline Gleyed Regosols are only found near seepages, soapholes, and springs. For this reason they are probably important with regard to groundwater discharge, but are essentially insignificant in terms of areal extent. A whitish surficial salt crust inevitably forms on these soils when the upper portion of the profiles become dry; thus, these soils are easily spotted in the field as well as on aerial photographs.

Soil Mapping Units

Examination of the soil map and topography map (Map 9, 2) reveals a definite relationship between the distribution pattern of

soils and elevation. This relationship may be illustrated by a catenary sequence (Figure 10) which shows the major map units as they occur along an east-west cross-section through the central part of the study area.

A topographic association which covers much of the central upland region consists of Eluviated Black, Truncated Eluviated Black, and Humic Eluviated Gleysol soils. The catenary sequence of these soils is illustrated in Figure 11. In some instances where the depression is comparatively dry, the transitional Gleyed Eluviated Black subgroup occupies the lowest portion.

Another similar catenary sequence is shown in Figure 12. This sequence is most common in the zone between the central ridge and the stream trenches in the east half of the study area. The depression in this sequence remains wet for most of the year.

Along the lower portions of the east slope, the gleysols in the above sequence (Figure 12) may be carbonated.

A typical distribution of soils that occur near depressions in the areas where solonetzic soils predominate is illustrated in Figure 13. All the soil individuals in this sequence (Figure 13) are characterized by one or more saline horizons.

Moist depressions located in areas of chernozemic soils (Figures 11 and 12) are characterized by a distinct, rapid change from poorly drained gleysolic soils to adjacent well drained chernozemic soils. In comparison, moist depressions located in areas of solonetzic soils (Figure 13) have a gradual extended change from poorly drained gleysolic soils to the moderately well drained solonetzic soils.

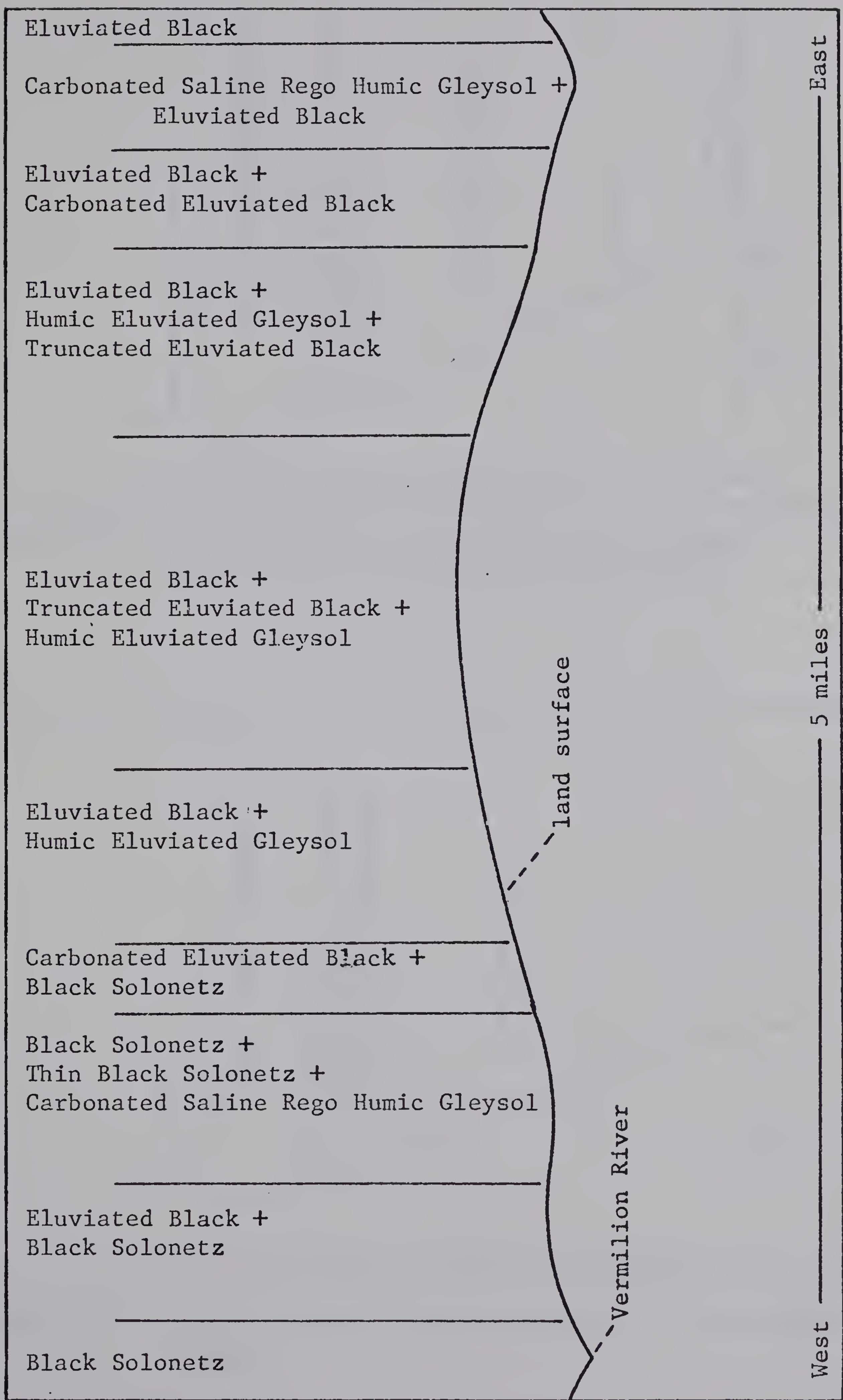


Figure 10. Distribution of Soils (Mapping Units) along West-East Cross-section through the Center of the Study Area.

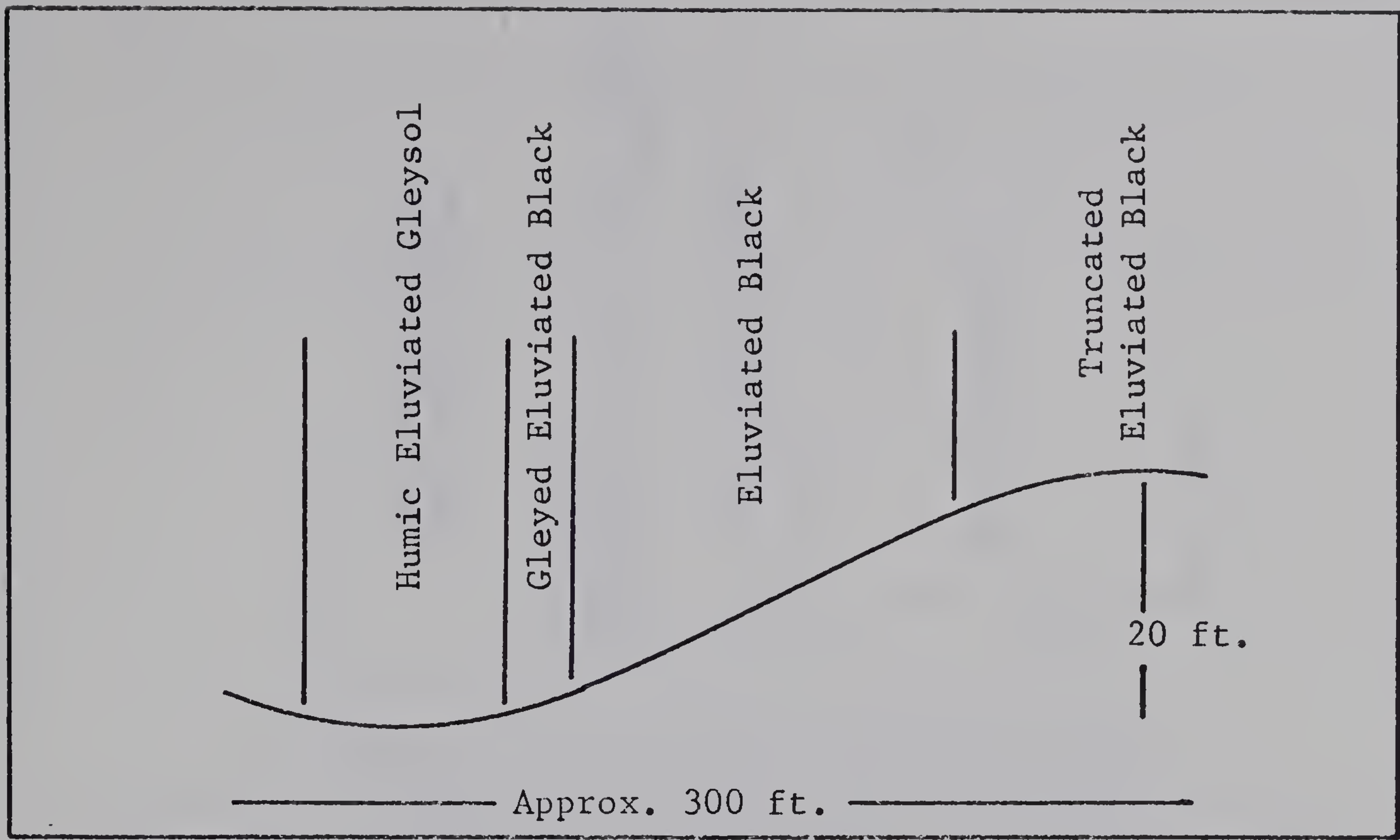


Figure 11. Catenary Sequence of Central Upland Region Corresponding to a Fast Recharge Slough.

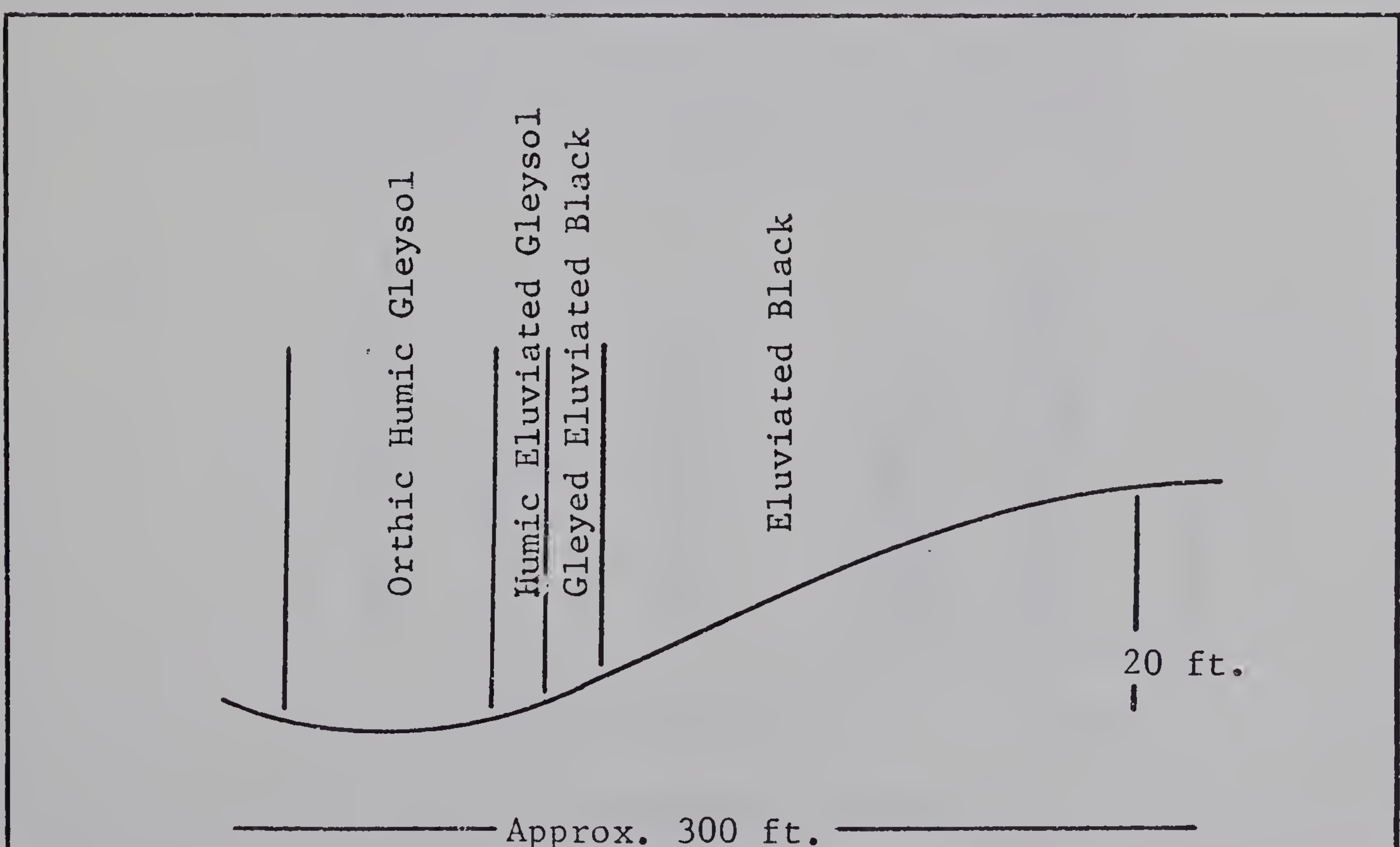


Figure 12. Catenary Sequence Corresponding to a Slow Recharge Slough.

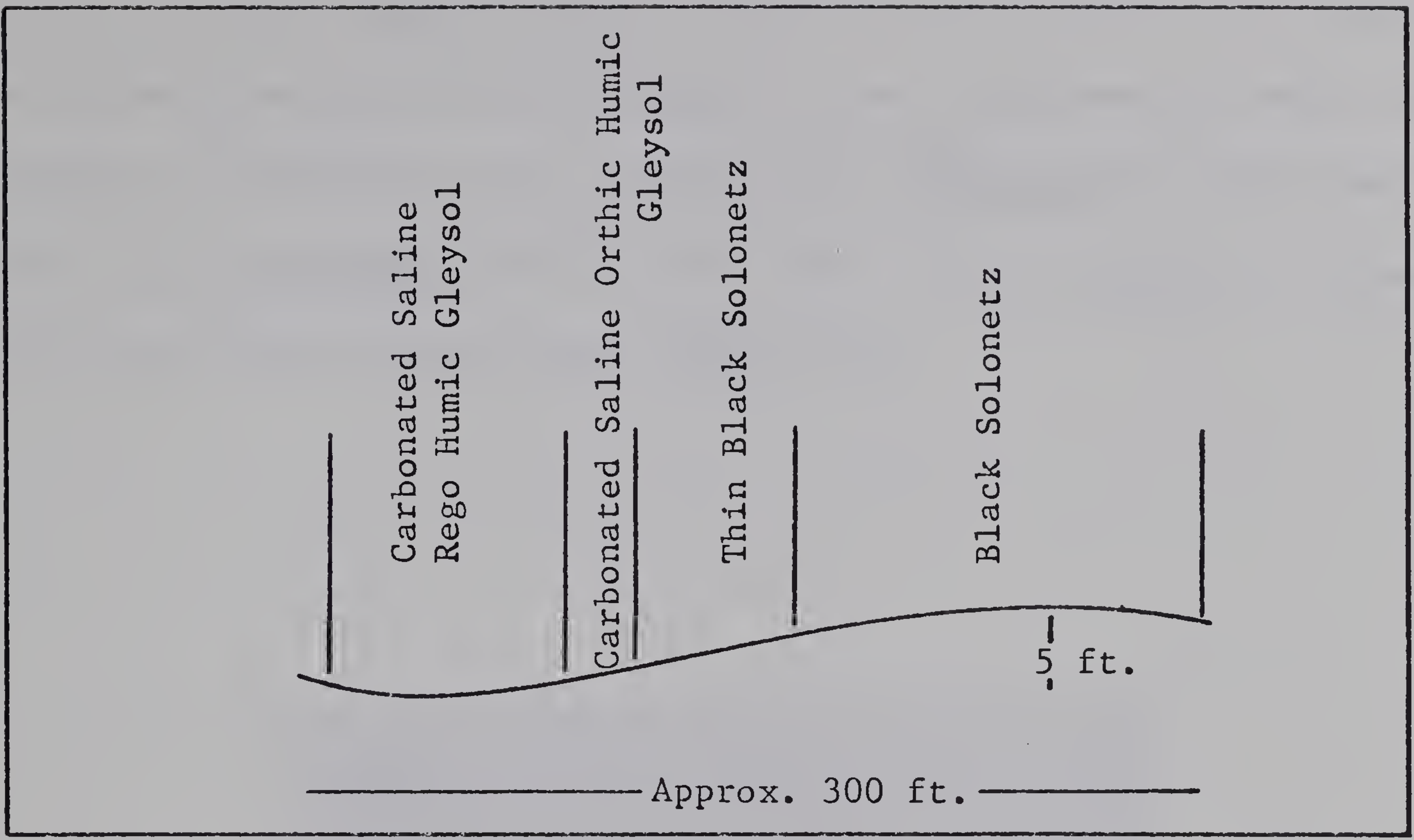


Figure 13. Soil Sequence Associated with Moist Depression in the Region of Solonetz Soils.

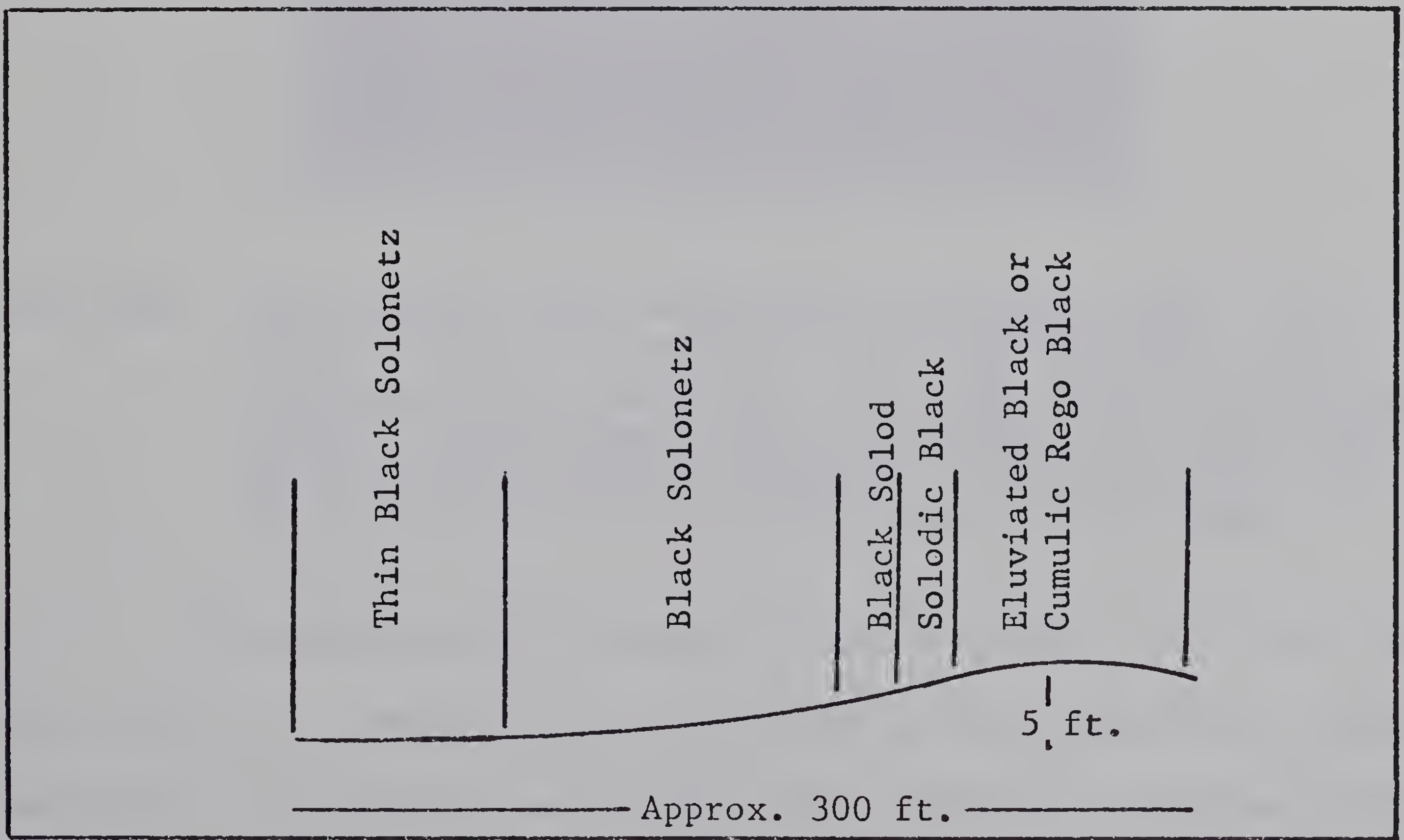


Figure 14. Soil Sequence which occurs in Relatively Dry Areas of Solonetz Soils.

A soil sequence that is common in the relatively dry areas of solonetz soils is shown in Figure 14, and represents the soils that develop in association with snowberry (S. occidentalis) patches and aspen (P. tremuloides) bluffs (Plate XII). This sequence may reoccur or it may adjoin the one above (Figure 13).

Plate XII. Aspen bluff in the intermediate discharge area. It is another "island" phenomena. Note the "stunted" growth of the aspen and the presence of gumweed (yellow-blossomed flower). Chernozemic soils occur within the aspen bluff and Thin Black Solonetz occurs in the grass-area. The lowest portion of the picture shows the road ditch.

Throughout much of the area along the lowest 1/3 of the west slope there is a complex pattern of solonetzic and chernozemic soils. Generally, the chernozems occupy the upper landscape positions and the solonetzic soils occupy the lower landscape positions but there are many exceptions to this pattern. For example, small patches or "islands" (1 or 2 acres) of solonetzic soils often occur in association with

chernozems in an upland position.

Most of the drainageways in the lower west region are characterized by a very complex pattern of many soils. Nearly all Gleysol, Chernozem, and Solonetz subgroups that were mapped in the study area occur in these drainageways. There is some relationship between type of soil individual and microrelief but no readily observable, reoccurring patterns were recognized. The major soils are shown in the map units but many integrades occur and often occupy more than 10 per cent of the delimited area.

VI. RELATIONSHIP BETWEEN SOIL AND GROUNDWATER

The soil map (Map 9) was compared to the map showing the distribution of recharge and discharge areas (Map 8) in order to establish the relationships that exist between soil pedogenesis and groundwater flow. The soil individuals that occur in each of the five areas and their significance with respect to groundwater flow are discussed below:

1. Recharge area

Soils occurring in this area include the Eluviated Black, Truncated Eluviated Black, Gleyed Eluviated Black, Humic Eluviated Gleysol, Humic Gleysol, and Rego Humic Gleysol. A lime accumulation layer, within a depth of about 40 inches, is present in the chernozemic soils but is usually absent in the gleysols. No saline horizons are present in any of these soils.

These soils are all indicative of groundwater recharge conditions. The absence of lime within the gleysolic profiles probably indicates rapid leaching and, therefore, rapid groundwater recharge. The lack of saline horizons in the soils indicates that there is no groundwater discharge.

2. Discharge area

The dominant soils that were mapped in this area include the Thin Black Solonetz, Black Solonetz, Carbonated Saline Gleysol, and Carbonated Saline Regosol. Saline horizons and a lime accumulation

layer are present in all the above soil individuals which may be interpreted to indicate groundwater discharge.

It is interesting to note that the saline horizons contain mainly Na_2SO_4. The high Na^+ concentration is expected since the discharging groundwaters contain dominantly Na^+. However, relative SO_4^{--} concentration is usually low in the discharging groundwaters yet its concentration in the soil greatly exceeds that of any other anion. This is probably due to the accumulation of SO_4^{--} over a long period of time. HCO_3^-, the relatively dominant anion in groundwaters, breaks down to CO_2 in the soil and therefore does not accumulate.

Occassionally, very small areas of chernozemic soils occur in the discharge area. These, as mentioned previously, occur in snowberry (S. occidentalis) patches. The presence of these soils may indicate very local downward or lateral movement of groundwater.

3. Indefinite area

Carbonated Eluviated Black, Rego Black, Eluviated Black, and Black Solonetz soils occur in this area. The presence of lime near or at the surfaces of these soils suggests lateral or upward moving groundwater. It appears that this area is situated in the uppermost portion of the discharge area and the upper boundary of these soils is the "midline".

4. Discharge with island recharge

A complex of Eluviated Black and Black Solonetz soils occupy a major portion of this area. Humic Eluviated Gleysols occur in some

of the depressions found at slightly elevated landscape positions whereas Saline Carbonated Humic Gleysols occur in depressions and drainageways at the lower landscape positions.

The "island" phenomena is supported by characteristics and distribution of the soils. Eluviated Black and Humic Eluviated Gleysols may indicate local recharge conditions whereas the Black Solonetz and Carbonated Saline Gleysols probably indicate groundwater discharge conditions. The soil characteristics associated with lateral movement of groundwater have not been established. However, one might expect that the Black Solod, Solodic Black, and Saline Eluviated Black soils indicate lateral groundwater movement in this area.

It is important to note that the elevation above datum of the water table which is controlled mainly by surface topography has less influence on the distribution of local recharge and discharge than one might expect as indicated by the complex soil patterns. Local vertical heterogeneities in texture and permeability of the parent material probably have a significant effect on soil development in this area.

5. Recharge with island discharge

The Eluviated Black soil is most extensive in this area. Small areas of Solodic Black and Black Solonetz soils occur. Humic Eluviated Gleysols and Humic Gleysols occupy most of the moist depressions but some Carbonated and a few Saline Carbonated Gleysols occur.

Humic Eluviated Gleysol, Humic Gleysol, and Eluviated Black soils probably indicate groundwater recharge in this area. The

Carbonated Gleysols appear to indicate local groundwater discharge or lateral flow and Saline Carbonated Gleysols apparently indicate local and intermediate groundwater discharge.

Proposed Classification

A proposed generalized classification for soils in terms of groundwater flow is presented in Table 6.

The potential for groundwater recharge and discharge is represented on the horizontal axis. The soils occurring near the center, horizontally, indicate "midline" conditions. Soils on the left suggest groundwater recharge whereas those on the right suggest groundwater discharge.

The vertical axis shows the comparative amount of water that may be expected to either enter or leave the saturated zone per unit area, of a particular soil.

Thus, a Humic Eluviated Gleysol with surface water as in spring is interpreted to indicate the maximum transmittance of water to the groundwater reservoir. This represents a fast recharge slough.

A Truncated Eluviated Black is "potentially" capable of transmitting a large amount of water through the profile to the groundwater reservoir but it is essentially dry throughout the year because of its slope position and, therefore, "contributes" little to groundwater.

POTENTIAL

<------------ GROUNDWATER RECHARGE   GROUNDWATER DISCHARGE ------------>

* Amount of Water Entering the Saturated Zone: Low <--- ---> High (left side)

* Amount of Water Leaving the Saturated Zone: High <--- ---> Low (right side)

Humic Eluviated Gleysol		Carbonated Saline Gleyed Regosol
Orthic Humic Gleysol		Carbonated Saline Rego Humic Gleysol
Rego Humic Gleysol		Carbonated Saline Humic Gleysol
	Carbonated Gleysols	
	Rego Black	
	Carbonated Eluviated Black	
Gleyed Eluviated Black		Thin Black Solonetz
Eluviated Black		Black Solonetz
Truncated Eluviated Black		Solodic Black and Black Solod

Table 6. Proposed Generalized Classification in terms of Spring Season Groundwater Flow Patterns at the Vegreville Study Area.
* Amount per unit area of the particular soil.

On the other hand, a Carbonated Saline Regosol is indicative of maximum removal of groundwater from the saturated zone. Solodic Black and Black Solod soils indicate near "midline" conditions in which there is little groundwater entering or leaving the flow system. In fact, these soils near the center may occur in areas where groundwater recharge and discharge conditions alternate during the year.

VII. SUMMARY AND CONCLUSIONS

In summary, field mapping in the Vegreville study area indicated a definite relationship between soil formation and natural groundwater movement. Soil salinity was perhaps the main factor indicating groundwater discharge from a soils point of view. Most chernozemic soils and the non-saline, non-carbonated gleysols observed in the area were interpreted to indicate groundwater recharge. Groundwater discharge was indicated by solonetzic and saline, carbonated gleysolic soils. An interpretive soil classification to be used as an aid to groundwater mapping was proposed.

The observed distribution of recharge and discharge areas within the study area supports the distribution that might be expected according to theoretical models (Tóth, 1962, 1963) and observations made elsewhere (Tóth, 1966a,b, 1968; Clissold, 1967), as discussed earlier.

Unfortunately, the piezometers (Appendix E) did not function properly and the actual groundwater flow pattern could not be determined for comparison with the predicted one.

In further investigations, careful attention should be given to other soil characteristics such as color, particularly mottling and gleying patterns, and structure since these may be very significant particularly in other areas where discharge waters may not be saline.

Gleysolic soils should be differentiated in soil mapping since they provide important clues that aid in outlining areas of groundwater recharge and discharge within both local and intermediate flow systems.

Piezometers installed at selected sites representing different soil sequences could provide detailed information on the relationship between groundwater and soils. For example, specific mottling patterns in gleysolic soils may indicate groundwater recharge, discharge, or through-flow which could be determined by piezometric measurements.

Meteorological equipment could be installed to aid in characterizing the complete hydrologic cycle for the study area. This would be desireable in order to obtain quantitative information related to groundwater recharge and discharge, and soil development.

Soil and groundwater mapping projects similar to this one should be conducted in other areas in order to test the proposed interpretive classification and to obtain more knowledge on the relationship between soils and groundwater.

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APPENDIX

KEY TO APPENDICES

Topography and Drainage Classes: According to N.S.S.C. (1968).

Profile Descriptions: According to N.S.S.C. (1968).

Abbreviations in Table of Data:

$CaCO_3$ Equiv. (%)	Calcium carbonate equivalent
Org. C (%)	Organic carbon
meq	Millequivalents
TEC	Total exchange capacity
EC	Electrical conductivity
S	Sand
Si	Silt
C	Clay
% Hygro. M.	Parent hygroscopic moisture
TDS	Total dissolved solids
epm	Equivalents per million

APPENDIX A-I

Morphological and Analytical Characteristics of Soils at the Vegreville Study Area

Eluviated Black Chernozem

Parent Material: Till
Topography: C
Elevation: 2,250 ft.
Location: NE 7-53-13-4 (piezometer nest no. 1)

Drainage Class: Well drained
Water Table (depth): 55 ft.
Vegetation: Alfalfa (*M. sativa*), Brome grass (*B. inermis*)

Horizon	Depth (in.)	Description
Ap	0- 6	Black (10 YR 2/1.5 m),very dark grayish brown (10 YR 3/2 d)clay loam; fine granular; very friable; abundant very fine roots; abrupt, wavy boundary; 4 to 8 inches thick; pH 6.6.
Bt1	6-15	Dark yellowish brown (10 YR 4/4 m),yellowish brown (10 YR 5/4 d)sandy clay; weak fine prismatic macrostructure, strong subangular blocky mesostructure; friable; plentiful very fine roots; gradual, wavy boundary; 8 to 10 inches thick; pH 6.5.
Bt2	15-26	Brown (10 YR 4/3 m,5/3 d)sandy clay loam; weak prismatic macrostructure, fine prismatic mesostructure; firm; few very fine roots; clear, wavy boundary; 9 to 13 inches thick; pH 6.1.
BC	26-28	Dark grayish brown (2.5 Y 4/2 m,d)clay; massive; firm; few very fine roots; clear, smooth boundary; 1 to 4 inches thick; pH 6.5.
Cca	28-53	Dark grayish brown (2.5 Y 4/2 m,d)clay; massive; firm; very few roots; clear, wavy boundary; 22 to 28 inches thick; pH 7.5.
Ck	53-75	Dark grayish brown (2.5 Y 4/2 m,d)clay loam; massive; friable; pH 7.4.

Horizon		Ap	Bt1	Bt2	BC	Cca	Ck
CHEMICAL ANALYSES							
pH		6.6	6.5	6.1	6.5	7.5	7.4
$CaCO_3$ Equiv. (%)		-	-	-	-	4.66	2.41
Org. C (%)		6.34	0.79	0.76	-	-	-
Total N (%)		0.46	0.06	0.05	-	-	-
Exchange	H^+	2.37	1.09	1.39	0.87	-	-
Analysis	Ca^{++}	27.4	14.2	13.4	19.4	39.0	26.0
(meq/100 g)	Mg^{++}	5.98	7.23	6.76	9.72	12.0	9.70
	Na^+	0.09	0.13	0.09	0.12	0.18	0.23
	K^+	0.60	0.31	0.27	0.46	0.51	0.42
	TEC	37.1	20.8	20.7	30.6	30.2	22.7
Soluble	Ca^{++}	2.43	1.08	1.12	2.00	2.00	3.18
Salts	Mg^{++}	0.98	0.68	0.72	1.28	1.29	2.51
(meq/l)	Na^+	0.33	0.41	0.48	0.52	0.66	0.95
	K^+	0.15	0.06	0.07	0.12	0.16	0.22
	CO_3^{--}	-	-	-	-	-	-
	HCO_3^-	2.75	1.25	1.00	2.10	2.80	3.60
	SO_4^{--}	-	-	-	-	-	2.00
EC (mmhos/cm)		0.33	0.20	0.23	0.35	0.37	0.65
PHYSICAL ANALYSES							
Particle	S	36	46	45	30	27	42
Size	Si	29	16	20	13	16	22
Analysis (%)	C	34	38	35	57	57	35
Texture		CL	SC	SCL	C	C	CL
Bulk Density (g/cc)		1.15	1.62	1.66	-	1.78	1.69
% Hygro. M		4.0	2.8	2.8	3.1	4.2	2.8

Eluviated Black Chernozem

Parent Material: Till
Topography: C
Elevation: 2,200 ft.
Location: SE 13-53-14-4
(piezometer nest no. 2)

Drainage Class: Moderately well drained
Water Table (depth): 13 ft.
Vegetation: Alfalfa (M. sativa)
Brome grass (B. inermis)

Horizon	Depth (in.)	Description
Ap	0-13	Black (10 YR 2/1.5 m), very dark grayish brown (10 YR 3/2 d) clay loam; fine granular; very friable; abundant very fine roots; clear, wavy boundary; 12 to 14 inches thick; pH 6.5.
Ahe	13-15	Dark brown (10 YR 3/3 m, 4/3 d) loam; fine granular; very friable; plentiful very fine roots; clear, wavy boundary; 1 1/2 to 2 1/2 inches thick; pH 6.9.
Bt	15-25	Dark yellowish brown (10 YR 4/4 m), yellowish brown (10 YR 5/4 d) clay loam; weak fine and medium prismatic macrostructure, fine subangular blocky mesostructure; friable; few, fine and very fine roots; gradual, smooth boundary; 8 to 12 inches thick; pH 7.3.
BC	25-40	Yellowish brown (10 YR 5/4 m), light yellowish brown (10 YR 6/4 d) loam; massive; friable; very few very fine roots; clear, wavy boundary; 12 to 18 inches thick; pH 7.7.
Cca1	40-52	Light olive brown (2.5 Y 5/4 m), light brownish gray (2.5 Y 6/2 d) sandy clay loam; massive; friable; clear, wavy boundary; 8 to 16 inches thick; pH 8.1.
Cca2	52-60	Dark grayish brown (2.5 Y 4/2 m) clay loam; massive; friable; pH 8.0.

Horizon		Ap	Ahe	Bt	BC	Cca1	Cca2
CHEMICAL ANALYSES							
pH		6.5	6.9	7.3	7.7	8.1	8.0
$CaCO_3$ Equiv. (%)		-	-	-	-	2.62	3.79
Org. C (%)		4.94	2.23	0.61	-	-	-
Total N (%)		0.42	0.16	0.06	-	-	-
Exchange	H^+	2.90	1.09	-	-	-	-
Analysis	Ca^{++}	21.4	12.8	11.4	-	-	-
(meq/100 g)	Mg^{++}	6.36	5.26	7.26	-	-	-
	Na^+	0.15	0.14	0.21	-	-	-
	K^+	0.30	0.20	0.26	-	-	-
	TEC	31.4	18.6	18.4	-	-	-
Soluble	Ca^{++}	1.12	1.25	1.18	1.25	2.31	1.37
Salts	Mg^{++}	0.68	0.82	0.86	1.23	3.60	1.89
(meq/l)	Na^+	0.44	0.52	0.74	3.04	7.47	1.69
	K^+	0.05	0.03	0.04	0.04	0.06	0.05
	CO_3^{--}	-	-	-	-	-	-
	HCO_3^-	1.50	1.50	1.80	3.40	5.00	3.30
	SO_4^{--}	-	-	-	1.0	4.0	0.12
EC (mmhos/cm)		0.20	0.20	0.24	0.50	1.1	0.47
PHYSICAL ANALYSES							
Particle	S	41	44	41	52	49	42
Size	Si	26	29	25	21	21	30
Analysis (%)	C	33	27	33	27	30	28
Texture		CL	L	CL	L	SCL	CL
Bulk Density (g/cc)		1.27	-	1.60	1.63	1.86	2.08
% Hygro. M		3.5	1.9	2.2	1.5	1.7	2.3

Gleyed Eluviated Black Chernozem

Parent Material: Till
Topography: C
Elevation: 2,150 ft.
Location: SW 13-53-14-4
(piezometer nest no. 3)

Drainage Class: Imperfectly drained
Water Table (depth): 7 ft.
Vegetation: Alfalfa (*M. sativa*)
Brome grass (*B. inermis*)

Horizon	Depth (in.)	Description
Ap	0-10	Very dark gray (10 YR 3/1 m), very dark grayish brown (10 YR 3/2 d) loam; fine granular; very friable; plentiful very fine roots; abrupt, wavy boundary; 9 to 11 inches thick; pH 6.7.
Aeg	10-12	Grayish brown (10 YR 5/2 m), light brownish gray (10 YR 6/2 d) loam; many fine distinct yellowish red (5 YR 4/6) mottles; weak fine platy; very friable; plentiful very fine roots; clear, wavy boundary; 1 to 2 inches thick; pH 6.7.
Btg	12-19	Brown (10 YR 4/3 m), pale brown (10 YR 6/3 d) sandy clay; many fine distinct yellowish red (5 YR 4/6 mottles; weak fine prismatic macrostructure, fine subangular blocky mesostructure; friable; few very fine roots; clear, wavy boundary; 6 to 8 inches thick; pH 6.9.
Bg	19-30	Dark yellowish brown (10 YR 4/4 m), light yellowish brown (10 YR 6/4 d) sandy clay loam; weak prismatic macrostructure, fine subangular blocky mesostructure; friable; few, fine and very fine roots; clear, smooth boundary; 10 to 12 inches thick; pH 7.6.
Ccag	30-40	Grayish brown (2.5 Y 5/2 m), light gray (2.5 Y 7/2 d) clay loam; massive; friable; few very fine roots; clear, smooth boundary; 8 to 12 inches thick; pH 7.9.
Ck	40+	

Horizon		Ap	Aeg	Btg	Bg	Ccag	Ck
CHEMICAL ANALYSES							
pH		6.7	6.7	6.9	7.6	7.9	7.8
$CaCO_3$ Equiv. (%)		-	-	-	-	8.45	4.12
Org. C (%)		6.42	1.08	0.60	-	-	-
Total N (%)		0.44	0.07	0.05	-	-	-
Exchange	H^+	2.93	0.98	0.68	-	-	-
Analysis	Ca^{++}	19.7	7.78	9.89	-	-	-
(meq/100 g)	Mg^{++}	4.59	2.46	3.32	-	-	-
	Na^+	0.18	0.10	0.14	-	-	-
	K^+	0.26	0.15	0.23	-	-	-
	TEC	28.6	10.6	13.4	-	-	-
Soluble	Ca^{++}	1.18	1.37	1.37	3.24	1.37	1.28
Salts	Mg^{++}	0.58	0.56	0.60	1.32	0.66	0.77
(meq/l)	Na^+	0.47	0.54	0.79	3.45	3.40	3.26
	K^+	0.04	0.04	0.05	0.05	0.03	0.08
	CO_3^{--}	-	-	-	-	-	-
	HCO_3^-	1.50	1.50	1.50	2.00	3.00	3.25
	SO_4^{--}	-	-	-	3.75	1.50	1.25
EC (mmhos/cm)		0.20	0.20	0.25	0.80	0.50	0.50
PHYSICAL ANALYSES							
Particle	S	50	52	48	50	43	54
Size	Si	24	25	13	16	20	20
Analysis (%)	C	26	22	38	34	37	26
Texture		L	L	SC	SCL	CL	SL
Bulk Density (g/cc)		1.35	-	1.73	1.76	1.96	-
% Hygro. M		3.4	1.1	1.7	2.2	2.1	1.2

Saline Eluviated Black Chernozem

Parent Material: Till
Topography: b
Elevation: 2,180 ft.
Location: NE 31-52-13-4

Drainage Class: Moderately well drained
Water Table (depth): 7 ft. (estimated)
Vegetation: Summerfallow

Horizon	Depth (in.)	Description
Ap	0-11	Black (10 YR 2/1.5 m), very dark gray (10 YR 3/1 d) loam; fine granular; loose; plentiful very fine roots; clear, wavy boundary; 8 to 14 inches thick; pH 6.3.
Ahe	11-16	Dark yellowish brown (10 YR 4/4 m), pale brown (10 YR 6/3 d) loam; fine platy; very friable; plentiful very fine roots; abrupt, smooth boundary; 2 to 6 inches thick; pH 6.8.
Bt	16-28	Dark brown (10 YR 3/3 m), light yellowish brown (10 YR 6/4 d) loam; fine prismatic macrostructure, subangular blocky mesostructure; plentiful very fine roots; abrupt, smooth boundary; 8 to 15 inches thick; pH 6.8.
Csak	28-34	Brown (10 YR 4/3 m), pale brown (10 YR 6/3 d) loam; weak fine subangular blocky; friable; very few very fine roots; clear, smooth boundary; 5 to 7 inches thick; pH 7.8.
Ccasa	34-56	Grayish brown (10 YR 5/2 m), pale brown (10 YR 6/3 d) loam; massive; friable; gradual, smooth boundary; 15 to 25 inches thick; pH 7.8.
Csk	56-65	Brown (10 YR 4/3 m) loam; amorphous; friable; pH 7.8.

Horizon		Ap	Ahe	Bt	Csak	Ccasa	Csk
CHEMICAL ANALYSES							
pH		6.3	6.8	6.8	7.8	7.8	7.8
$CaCO_3$ Equiv. (%)		-	-	-	2.51	6.62	3.01
Org. C (%)		6.14	1.03	0.71	-	-	-
Total N (%)		0.49	0.09	0.05	-	-	-
Exchange	H^+	3.88	1.07	0.68	-	-	-
Analysis	Ca^{++}	23.6	8.29	9.02	-	-	-
(meq/100 g)	Mg^{++}	6.89	5.43	11.0	-	-	-
	Na^+	0.27	0.49	1.60	-	-	-
	K^+	0.30	0.21	0.26	-	-	-
	TEC	35.7	14.0	19.2	-	-	-
Soluble	Ca^{++}	-	-	-	22.0	20.0	25.0
Salts	Mg^{++}	-	-	-	55.7	44.9	36.1
(meq/1)	Na^+	-	-	-	31.7	37.4	15.9
	K^+	-	-	-	0.33	0.36	0.43
	CO_3^{--}	-	-	-	-	-	-
	HCO_3^-	-	-	-	2.54	1.48	2.00
	SO_4^{--}	-	-	-	119	125	53.7
EC (mmhos/cm)		-	-	-	6.8	6.5	3.6
PHYSICAL ANALYSES							
Particle	S	40	45	45	46	42	48
Size	Si	40	39	32	36	34	32
Analysis (%)	C	20	16	23	18	24	20
Texture		L	L	L	L	L	L
Bulk Density (g/cc)		1.22	1.47	1.55	-	1.71	-
% Hygro. M		5.2	1.3	2.2	2.1	2.3	1.3

Cumulic Rego Black Chernozem

Parent Material: Till
Topography: b
Elevation: 2,060 ft.
Location: NW 24-53-14-4

Drainage Class: Moderately well drained
Water Table (depth): 8 ft. (estimated).
Vegetation: Buckbrush (*S. occidentalis*)

Horizon	Depth (in.)	Description
Ah1	0-15	Very dark gray (10 YR 3/1 m), dark grayish brown (10 YR 4/2 d) sandy loam; weak fine granular; loose; abundant fine roots, plentiful medium roots; gradual, wavy boundary; 10 to 20 inches thick; pH 6.2.
Ahk	15-32	Very dark gray (10 YR 3/1 m), dark grayish brown (10 YR 4/2 d) sandy loam; weak fine granular; loose; abundant fine roots; plentiful medium roots; gradual, wavy boundary; 10 to 20 inches thick; pH 7.5.
ACk	32-50	Very dark grayish brown (10 YR 3/2 m), grayish brown (10 YR 5/2 d) sandy loam; very friable; few fine roots; clear, wavy boundary; 15 to 25 inches thick; pH 8.0.
Cca	50-58+	Yellowish brown (10 YR 5/4 m), very pale brown (10 YR 7/3 d) sandy loam; amorphous; pH 8.1.

Horizon		Ah1	Ahk	ACk	Cca
CHEMICAL ANALYSES					
pH		6.2	7.5	8.0	8.1
$CaCO_3$ Equiv. (%)		-	0.11	1.44	5.33
Org. C (%)		3.00	1.61	1.00	-
Total N (%)		0.24	0.14	0.09	-
Exchange	H^+	2.23	-	-	-
Analysis	Ca^{++}	14.7	17.1	-	-
(meq/100 g)	Mg^{++}	3.20	3.18	-	-
	Na^+	0.07	0.13	-	-
	K^+	0.31	0.28	-	-
	TEC	18.6	16.9	-	-
Soluble	Ca^{++}	-	4.00	3.75	3.00
Salts	Mg^{++}	-	1.39	1.31	1.80
(meq/1)	Na^+	-	0.70	1.05	1.50
	K^+	-	0.20	0.22	0.18
	CO_3^{--}	-	-	-	-
	HCO_3^-	-	4.35	3.92	3.24
	SO_4^{--}	-	-	-	2.75
EC (mmhos/cm)		-	0.46	0.50	0.60
PHYSICAL ANALYSES					
Particle	S	67	67	69	71
Size	Si	23	23	29	20
Analysis (%)	C	10	10	10	9
Texture		SL	SL	SL	SL
Bulk Density (g/cc)		1.25	-	-	1.67
% Hygro. M		2.4	2.2	1.2	0.9

Black Solonetz

Parent Material: Till
Topography: b
Elevation: 2,070 ft.
Location: SE 11-53-14-4

Drainage Class: Moderately well drained
Water Table (depth): 6 ft. (estimated).
Vegetation: Native grasses

Horizon	Depth (in.)	Description
Ah	0- 5	Very dark gray (10 YR 3/1 m), dark gray (10 YR 4/1 d) loam; fine granular; very friable; abundant, fine and very fine roots; abrupt, wavy boundary; 4 to 8 inches thick; pH 5.8.
Ae	5- 7	Dark brown (10 YR 3/3 m), gray (10 YR 5/1 d) loam; fine platy; very friable; abundant fine roots; abrupt, wavy boundary; 1 to 2 inches thick; pH 6.7.
Bntk	7-12	Dark grayish brown (10 YR 4/2 m), grayish brown (10 YR 5/2 d) ped interiors, very dark gray (10 YR 3/1 m,d) ped surfaces; loam; strong coarse columnar round top macrostructure, strong fine subangular blocky mesostructure; very firm; plentiful, fine and very fine exped roots; clear, smooth boundary; 5 to 7 inches thick; pH 7.7.
Csak	12-20	Dark grayish brown (10 YR 4/2 m), grayish brown (10 YR 5/2 d) clay loam; amorphous; very friable; gradual, wavy boundary; 6 to 10 inches thick; pH 7.7.
Ccas	20-32	Dark grayish brown (10 YR 4/2 m), grayish brown (10 YR 5/2 d) loam; amorphous; friable; diffuse, smooth boundary; 10 to 14 inches thick; pH 8.5.
Ccasa	32-58	Dark grayish brown (10 YR 4/2 m), pale brown (10 YR 6/3 d) loam; amorphous; firm; diffuse, smooth boundary; 25 to 30 inches thick; pH 8.1.
Csk	58-75	Dark grayish brown (10 YR 4/2 m), grayish brown (10 YR 5/2 d) loam; amorphous; firm; pH 8.5.

Horizon		Ah	Ae	Bntk	Csak	Ccas	Ccasa	Csk
CHEMICAL ANALYSES								
pH		5.8	6.7	7.7	7.7	8.5	8.1	8.5
$CaCO_3$ Equiv. (%)		-	-	0.14	0.23	4.22	4.42	3.08
Org. C (%)		4.87	2.20	-	-	-	-	-
Total N (%)		0.41	0.20	0.15	-	-	-	-
Exchange	H^+	8.42	2.50	-	-	-	-	-
Analysis	Ca^{++}	4.13	3.77	-	-	-	-	-
(meq/100 g)	Mg^{++}	1.90	2.60	-	-	-	-	-
	Na^+	1.58	4.16	-	-	-	-	-
	K^+	0.23	0.19	-	-	-	-	-
	TEC	20.0	12.6	-	-	-	-	-
Soluble	Ca^{++}	-	-	2.75	22.0	1.90	22.0	1.12
Salts	Mg^{++}	-	-	4.59	26.2	3.80	15.2	1.65
(meq/1)	Na^+	-	-	60.9	142	60.9	97.8	48.9
	K^+	-	-	0.13	0.31	0.13	0.29	0.18
	CO_3^{--}	-	-	-	-	-	-	-
	HCO_3^-	-	-	1.75	1.78	1.80	1.18	3.76
	SO_4^{--}	-	-	62.5	172	71.2	145	55.0
EC (mmhos/cm)		-	-	6.2	14	6.0	10	4.8
PHYSICAL ANALYSES								
Particle	S	40	39	32	25	46	49	48
Size	Si	44	47	42	44	29	30	32
Analysis (%)	C	16	14	26	31	25	21	20
Texture		L	L	L	CL	L	L	L
Bulk Density (g/cc)		1.14	-	1.49	1.70	1.84	1.95	2.00
% Hygro. M		3.1	1.4	2.2	3.5	1.8	1.6	1.0

Black Solonetz

Parent Material: Till
Topography: b
Elevation: 2,110 ft.
Location: SW 13-53-14-4

Drainage Class: Moderately well drained
Water Table (depth): 6 ft. (estimated)
Vegetation: Native grasses

Horizon	Depth (in.)	Description
Ah	0- 9 1/2	Black (10 YR 2/1 m), very dark gray (10 YR 3/1 d) loam; weak fine granular; loose; abundant very fine roots; abrupt, wavy boundary; 8 to 10 inches thick; pH 6.3.
Ae	9 1/2-10	Dark grayish brown (10 YR 4/2 m), light brownish gray (10 YR 6/2 d) loam; weak fine platy; loose; abundant very fine roots; abrupt, irregular boundary; 1/2 to 1 1/2 inches thick; pH 6.5.
Bntk	10-19	Dark yellowish brown (10 YR 4/4 m), yellowish brown (10 YR 5/4 d) ped interiors, very dark gray (10 YR 3/1 m), dark gray (10 YR 4/1 d) ped surfaces; loam; strong columnar round top macrostructure, strong subangular blocky mesostructure; very firm; plentiful very fine exped roots; clear, smooth boundary; 8 to 12 inches thick; pH 7.1.
BCk	19-21	Dark brown (10 YR 3/3 m) loam; massive; friable; few very fine roots; clear, smooth boundary; 2 to 4 inches thick.
Ccasa	21-56	Dark brown (10 YR 4/3 m), light yellowish brown (10 YR 6/4 d) loam; massive; friable; gradual, smooth boundary; 30 to 40 inches thick; pH 7.8.
Csk	56-80+	Dark brown (10 YR 4/3 m) loam; massive; firm; pH 7.7.

Horizon		Ah	Ae	Bnt	Ccasa	Csk
CHEMICAL ANALYSES						
pH		6.3	6.5	7.1	7.8	7.7
$CaCO_3$ Equiv. (%)		-	-	0.43	10.2	5.00
Org. C (%)		5.45	1.66	0.55	-	-
Total N (%)		0.50	0.15	0.08	-	-
Exchange	H^+	8.42	2.83	-	-	-
Analysis	Ca^{++}	10.7	4.79	5.10	-	-
(meq/100 g)	Mg^{++}	3.94	2.69	8.58	-	-
	Na^+	1.36	2.30	6.23	-	-
	K^+	0.21	0.21	0.40	-	-
	TEC	27.5	11.4	18.5	-	-
Soluble	Ca^{++}	-	-	-	21.0	15.0
Salts	Mg^{++}	-	-	-	26.2	13.9
(meq/1)	Na^+	-	-	-	92.6	67.8
	K^+	-	-	-	0.33	0.36
	CO_3^{--}	-	-	-	-	-
	HCO_3^-	-	-	-	1.58	2.40
	SO_4^{--}	-	-	-	140	108
EC (mmhos/cm)		-	-	-	10	7.7
PHYSICAL ANALYSES						
Particle	S	46	43	43	51	53
Size	Si	38	47	31	28	28
Analysis (%)	C	16	10	26	21	19
Texture		L	L	L	L	L
Bulk Density (g/cc)		1.34	-	1.68	1.90	1.90
% Hygro. M		4.1	1.1	1.7	1.2	1.0

Thin Black Solonetz

Parent Material: Till
Topography: b
Elevation: 2,100 ft.
Location: NE 11-53-14-4 (piezometer nest no. 4)

Drainage Class: Imperfectly to moderately well drained
Water Table (depth): 3 ft.
Vegetation: Brome grass (*B. inermis*), Foxtail (*Hordeum jubatum*)

Horizon	Depth (in.)	Description
Ap	0- 4	Very dark brown (10 YR 2/2 m), dark grayish brown (10 YR 4/2 d) loam; coarse granular; slightly hard; abundant very fine roots; abrupt, wavy boundary; 3 to 4 inches thick; pH 6.3.
Ae	4- 4 1/2	Dark grayish brown (10 YR 4/2 m), light brownish gray (10 YR 6/2 d) sandy loam; fine platy; soft; abundant very fine roots; abrupt, wavy boundary; 1/4 to 1 inch thick.
Bnts	4 1/2-10	Dark brown (10 YR 4/3 m), dark grayish brown (10 YR 4/2 d) clay loam; very dark gray (10 YR 3/1 m,d) ped surfaces; strong coarse columnar macrostructure, strong fine angular blocky mesostructure; very firm; plentiful very fine exped roots; clear, smooth boundary; 5 to 7 inches thick; pH 7.3.
Csak	10-18	Very dark grayish brown (10 YR 3/2 m), dark grayish brown (10 YR 4/2 d) clay; massive; very friable; very few roots; clear, wavy boundary; 7 to 9 inches thick; pH 8.0.
Csk	18-30	Dark grayish brown (2.5 Y 4/2 m), grayish brown (2.5 Y 5/2 d) sandy clay; massive; very friable; clear, wavy boundary; 8 to 12 inches thick; pH 8.3.
Ccas	30-36	Dark grayish brown (2.5 Y 4/2 m), light brownish gray (2.5 Y 6/2 d) sandy clay loam; massive; very friable; clear, wavy boundary; 6 to 8 inches thick; pH 8.2.
Csk	36+	Dark grayish brown (2.5 Y 4/2 m) sandy clay loam; massive; very friable; pH 8.0.

Horizon		Ap	Bnts	Csak	Csk	Ccas	Csk
CHEMICAL ANALYSES							
pH		6.3	7.3	8.0	8.3	8.2	8.0
$CaCO_3$ Equiv. (%)		-	-	0.48	2.27	4.22	3.74
Org. C (%)		5.83	2.08	-	-	-	-
Total N (%)		0.39	0.18	-	-	-	-
Exchange	H^+	4.61	-	-	-	-	-
Analysis	Ca^{++}	6.20	6.65	-	-	-	-
(meq/100 g)	Mg^{++}	2.54	5.66	-	-	-	-
	Na^+	4.41	11.6	-	-	-	-
	K^+	0.25	0.23	-	-	-	-
	TEC	18.7	21.7	-	-	-	-
Soluble	Ca^{++}	0.50	2.12	19.0	18.5	19.5	19.5
Salts	Mg^{++}	0.50	3.25	25.5	13.0	10.1	9.46
(meq/l)	Na^+	2.93	69.6	239	120	97.8	120
	K^+	0.09	0.05	0.12	0.11	0.16	0.19
	CO_3^-	-	-	-	-	-	-
	HCO_3^-	1.75	5.50	2.00	1.85	1.60	1.75
	SO_4^{--}	6.50	50.0	181	156	119	125
EC (mmhos/cm)		1.3	6.0	20	11	10	10
PHYSICAL ANALYSES							
Particle	S	41	36	25	47	47	51
Size	Si	33	32	30	16	20	21
Analysis (%)	C	26	32	45	37	33	28
Texture		L	CL	C	SC	SCL	SCL
Bulk Density (g/cc)		1.32	1.65	1.75	2.01	-	2.11
% Hygro. M		2.9	1.9	5.4	2.6	2.9	1.7

Thin Black Solonetz

Parent Material: Till
Topography: b
Elevation: 2,0/0 ft.
Location: SE 11-53-14-4

Drainage Class: Imperfectly to moderately well drained
Water Table (depth): 3 ft. (estimated)
Vegetation: Native grasses and sedges

Horizon	Depth (in.)	Description
Ah	0- 4	Very dark gray (10 YR 3/1 m), dark gray (10 YR 4/1 d) loam; weak fine granular; very friable; abundant, fine and very fine roots; clear, wavy boundary; 2 to 4 inches thick; pH 6.2.
Ae	4- 6	Brown (10 YR 4/3 m), grayish brown (10 YR 5/2 d) sandy loam; weak fine platy; very friable; abundant, fine and very fine roots; abrupt, wavy boundary; 1 to 2 inches thick; pH 6.9.
Bntks	6-13	Dark grayish brown (10 YR 4/2 m), brown (10 YR 4/3 d) ped interiors, black (10 YR 2/1 m, d) ped surfaces; sandy clay loam; strong coarse columnar round top structure; strong subangular blocky mesostructure; very firm; plentiful fine exped roots; clear, wavy boundary; 6 to 8 inches thick; pH 7.5.
Csak	13-18	Dark brown (10 YR 4/3 m), light yellowish brown (10 YR 6/4 d) loam; amorphous; friable; clear, wavy boundary; 4 to 6 inches thick; pH 8.2.
Ccas	18-33	Dark grayish brown (10 YR 4/2 m), light brownish gray (10 YR 6/2 d) loam; amorphous; friable; diffuse smooth boundary; 12 to 16 inches thick; pH 8.9.
Csak	33+	Dark grayish brown (2.5 Y 4/2 m), grayish brown (10 YR 5/2 d) loam; amorphous; firm; pH 8.1.

Horizon		Ah	Ae	Bntks	Csak	Ccas	Csak
CHEMICAL ANALYSES							
pH		6.2	6.9	7.5	8.2	8.9	8.0
$CaCO_3$ Equiv. (%)		-	-	0.10	1.24	6.34	3.14
Org. C (%)		5.53	1.58	-	-	-	-
Total N (%)		-	0.16	0.12	-	-	-
Exchange	H^+	7.44	1.93	-	-	-	-
Analysis	Ca^{++}	7.25	2.02	3.30	-	-	-
(meq/100 g)	Mg^{++}	2.55	1.66	7.09	-	-	-
	Na^+	1.12	3.41	13.3	-	-	-
	K^+	0.50	0.29	0.86	-	-	-
	TEC	22.9	8.09	20.5	-	-	-
Soluble	Ca^{++}	-	-	1.12	12.0	0.75	10.0
Salts	Mg^{++}	-	-	3.36	23.6	3.03	17.0
(meq/1)	Na^+	-	-	60.9	163	66.3	106
	K^+	-	-	0.28	0.61	0.23	0.64
	CO_3^{--}	-	-	-	-	-	-
	HCO_3^-	-	-	6.30	1.96	2.82	1.39
	SO_4^{--}	-	-	71.2	162	71.2	147
EC (mmhos/cm)		-	-	5.9	15	6.2	11
PHYSICAL ANALYSES							
Particle	S	50	61	49	45	43	45
Size	Si	35	29	25	34	32	32
Analysis (%)	C	15	10	26	21	25	23
Texture		L	SL	SCL	L	L	L
Bulk Density (g/cc)		1.17	-	1.58	1.65	1.73	1.89
% Hygro. M		4.3	0.9	2.2	2.6	1.5	1.7

Thin Black Solonetz

Parent Material: Sorted Material
Topography: b
Elevation: 2,100 ft.
Location: SW 13-53-14-4

Drainage Class: Imperfectly to moderately well drained
Water Table (depth): 4 ft. (estimated).
Vegetation: Native grasses, Gumweed (G. perennis)

Horizon	Depth (in.)	Description
Ah	0- 3	Black (10 YR 2/1 d), dary gray (10 YR 4/1 d) loam; fine granular; very friable; abundant fine and very fine roots; abrupt, wavy boundary; 2 to 4 inches thick; pH 6.1.
Aek	3- 4	Dark grayish brown (10 YR 4/2 m), grayish brown (10 YR 5/2 d) loam; fine granular to weak platy; very friable; abundant very fine roots; abrupt, wavy boundary; 1/2 to 1 1/2 inches thick; pH 7.5.
Bntks	4- 9	Yellowish brown (10 YR 5/4 m,d) ped interiors, very dark gray (10 YR 3/1 m,d) ped surfaces; loam; strong coarse columnar round top macrostructure, strong subangular blocky mesostructure; very firm; plentiful very fine exped roots; clear, smooth boundary; 4 to 7 inches thick; pH 8.2.
Ccasa	9-28	Yellowish brown (10 YR 5/4 m), pale brown (10 YR 6/3 d) clay loam; massive; firm; gradual, smooth boundary; 15 to 20 inches thick; pH 8.9.
IICsk	28-52+	Till; pH 8.8.

Horizon		Ah	Aek	Bntks	Ccasa	IICsk
CHEMICAL ANALYSES						
pH		6.1	7.5	8.2	8.9	8.8
$CaCO_3$ Equiv. (%)		-	0.30	0.74	8.88	4.35
Org. C (%)		8.56	2.15	0.72	-	-
Total N (%)		0.67	0.26	-	-	-
Exchange	H^+	6.68	-	-	-	-
Analysis	Ca^{++}	11.5	5.85	-	-	-
(meq/100 g)	Mg^{++}	4.87	3.33	-	-	-
	Na^+	4.20	6.32	-	-	-
	K^+	0.96	0.18	-	-	-
	TEC	30.6	13.3	-	-	-
Soluble	Ca^{++}	-	-	1.12	1.50	0.75
Salts	Mg^{++}	-	-	1.39	0.90	0.53
(meq/1)	Na^+	-	-	48.7	84.8	38.5
	K^+	-	-	0.06	0.09	0.08
	CO_3^{--}	-	-	-	-	-
	HCO_3^-	-	-	12.2	3.74	5.65
	SO_4^{--}	-	-	47.5	108	40.6
EC (mmhos/cm)		-	-	4.7	8.0	3.9
PHYSICAL ANALYSES						
Particle	S	33	44	40	30	49
Size	Si	49	46	37	43	30
Analysis (%)	C	18	10	23	27	21
Texture		L	L	L	CL	L
Bulk Density (g/cc)		1.03	-	1.51	1.75	1.98
% Hygro. M		11	2.2	1.6	0.8	0.9

Black Solod

Parent Material: Till
Topography: b
Elevation: 2,060 ft.
Location: SE 15-53-14-4
(piezometer nest no. 5)

Drainage Class: Moderately well drained
Water Table (depth): 9 ft.
Vegetation: Snowberry (S. occidentalis), Native grasses.

Horizon	Depth (in.)	Description
Ah	0- 7	Very dark gray (10 YR 3/1 m), dark grayish brown (10 YR 4/2 d) loam; weak fine granular; soft; abundant very fine roots; clear, wavy boundary; 6 to 8 inches thick; pH 6.1.
Ae	7- 9	Yellowish brown (10 YR 5/4 m), grayish brown (10 YR 5/2 d) loam; weak fine platy; soft; plentiful very fine roots; clear, wavy boundary; 1 1/2 to 2 1/2 inches thick; pH 6.4.
AB	9-10	Dark grayish brown (10 YR 4/2 m), grayish brown (10 YR 5/2 d) loam; fine subangular blocky; slightly hard; plentiful very fine roots; clear, wavy boundary; 1/2 to 1 1/2 inches thick.
Bnt	10-16	Dark brown (10 YR 4/3 m,d) loam; very dark grayish brown (10 YR 3/2 m), dark grayish brown (10 YR 4/2 d) ped surfaces; columnar macrostructure, strong subangular blocky mesostructure; hard; plentiful, very fine and fine exped roots; clear, smooth boundary; 5 to 7 inches thick; pH 6.7.
BCk	16-20	Dark brown (10 YR 4/3 m), dark grayish brown (2.5 Y 4/2 d) loam; columnar; firm; plentiful very fine roots; clear, smooth boundary; 3 1/2 to 5 inches thick; pH 7.4.
Csaca	20-40	Yellowish brown (10 YR 5/4 m), pale brown (10 YR 6/3 d) loam; massive; firm; few very fine roots; clear, smooth boundary; 18 to 22 inches thick; pH 7.7.

Horizon		Ap	Ae	Bnt	BCk	Csaca
CHEMICAL ANALYSES						
pH		6.1	6.4	6.7	7.4	7.7
$CaCO_3$ Equiv. (%)		-	-	-	0.65	6.98
Org. C (%)		7.68	1.86	1.12	-	-
Total N (%)		0.56	0.16	0.10	-	-
Exchange	H^+	4.90	1.96	0.88	-	-
Analysis	Ca^{++}	13.2	6.05	11.7	12.6	-
(meq/100 g)	Mg^{++}	4.46	2.48	8.61	7.91	-
	Na^+	0.15	0.33	1.56	1.38	-
	K^+	0.49	0.17	0.44	0.40	-
	TEC	27.0	11.2	23.4	20.0	-
Soluble	Ca^{++}	0.87	0.54	0.62	1.81	20.5
Salts	Mg^{++}	0.55	0.45	0.60	1.50	18.1
(meq/1)	Na^+	0.36	0.87	2.99	4.35	24.8
	K^+	0.12	0.03	0.05	0.09	0.27
	CO_3^{--}	-	-	-	-	-
	HCO_3^-	0.85	0.90	2.25	5.50	2.50
	SO_4^{--}	-	-	-	2.25	65.6
EC (mmhos/cm)		0.20	0.10	0.36	0.84	4.7
PHYSICAL ANALYSES						
Particle	S	44	44	25	34	41
Size	Si	31	37	25	19	19
Analysis (%)	C	25	19	50	47	40
Texture		L	L	C	C	C
Bulk Density (g/cc)		1.00	-	1.73	1.81	1.81
% Hygro. M		3.0	1.1	3.0	1.6	1.8

Humic Eluviated Gleysol

Parent Material: Till
Topography: b
Elevation: 2,240 ft.
Location: SE 19-53-13-4

Drainage Class: Poorly drained
Water Table (depth): 5 ft. (estimated)
Vegetation: Awned sedge (*C. atherodes*)

Horizon	Depth (in.)	Description
Ah	0- 4	Very dark grayish brown (10 YR 3/2 m), grayish brown (10 YR 5/2 d) loam; fine granular; friable; abundant, fine and very fine roots; clear, smooth boundary; 4 to 6 inches thick; pH 6.0.
Aheg	4- 7	Very dark grayish brown (10 YR 3/2 m), light brownish gray (10 YR 6/2 d) loam; few, fine, faint brown mottles; weak fine platy; friable; abundant, fine and very fine roots; abrupt, smooth boundary; 2 to 4 inches thick; pH 6.3.
Aeg	7-10	Grayish brown (10 YR 5/2 m), light gray (10 YR 6/1 d) loam; common, fine, distinct reddish brown mottles; platy; friable; abundant fine roots; clear, smooth boundary; 2 to 4 inches thick; pH 6.6.
Btg1	10-22	Dark gray (5 Y 4/1 m), gray (5 Y 6/1 d) loam; few, fine faint reddish brown mottles; fine subangular blocky; firm; plentiful fine roots; diffuse, smooth boundary; 10 to 14 inches thick; pH 6.3.
Btg2	22-33	Gray (5 Y 5/1 m, 6/1 d) clay loam; common, fine, distinct yellowish brown mottles; weak subangular blocky; firm; very few roots; diffuse, smooth boundary; 10 to 14 inches thick; pH 6.6.
Cg	33+	Gray (5 Y 5/1 m, 6/1 d) sandy loam; amorphous, friable; pH 7.0.

Horizon		Ahg	Aheg	Aeg	Btg1	Btg2	Cg
CHEMICAL ANALYSES							
pH		6.0	6.3	6.6	6.3	6.6	7.0
$CaCO_3$ Equiv. (%)		-	-	-	-	-	-
Org. C (%)		6.74	3.10	0.50	0.26	-	-
Total N (%)		0.56	0.28	0.05	0.03	-	-
Exchange	H^+	5.45	3.11	1.36	1.07	1.19	0.98
Analysis	Ca^{++}	21.3	11.9	5.52	10.6	15.2	8.14
(meq/100 g)	Mg^{++}	4.80	2.25	1.44	3.42	4.56	2.92
	Na^+	0.07	0.06	0.04	0.04	0.30	0.09
	K^+	2.20	1.72	1.37	1.07	2.23	0.68
	TEC	37.7	18.7	8.99	17.3	25.4	12.3
Soluble	Ca^{++}	-	-	-	-	-	-
Salts	Mg^{++}	-	-	-	-	-	-
(meq/1)	Na^+	-	-	-	-	-	-
	K^+	-	-	-	-	-	-
	CO_3^{--}	-	-	-	-	-	-
	HCO_3^-	-	-	-	-	-	-
	SO_4^{--}	-	-	-	-	-	-
EC (mmhos/cm)		-	-	-	-	-	-
PHYSICAL ANALYSES							
Particle	S	31	40	38	48	31	57
Size	Si	46	46	46	30	35	30
Analysis (%)	C	23	14	16	22	34	13
Texture		L	L	L	L	CL	SL
Bulk Density (g/cc)		0.75	-	1.55	1.65	1.72	1.75
% Hygro. M		5.8	2.4	0.8	2.3	3.4	2.2

Saline Carbonated Regosol

Parent Material: Till
Topography: b
Elevation: 2,100 ft.
Location: NE 11-53-14-4

Drainage Class: Imperfectly drained
Water Table (depth): 2 ft. (estimated).
Vegetation: Red samphire (*S. rubra*)

Horizon	Depth (in.)	Description
I	0- 3	Dark grayish brown (10 YR 4/2 m), grayish brown (10 YR 5/2 d) sandy loam; amorphous; slightly hard; very few very fine roots; abrupt, smooth boundary; 1 to 3 inches thick; pH 9.0.
II	3- 7	Very dark grayish brown (10 YR 3/2 m), dark grayish brown (10 YR 4/2 d) sandy loam; weak columnar flat top; hard; clear, wavy boundary; 3 to 5 inches thick; pH 10.0.
III	7-11	Dark brown (10 YR 3/3 m), dark grayish brown (10 YR 4/2 d) sandy clay loam; amorphous, friable; clear, wavy boundary; 1 to 4 inches thick; pH 10.0.
IV	11-26	Yellowish brown (10 YR 5/4 m), pale brown (10 YR 6/3 d) sandy loam; amorphous; friable; clear, wavy boundary; 12 to 15 inches thick; pH 9.9.
V	26-40+	Dark grayish brown (10 YR 4/2 m) sandy loam; amorphous; firm; pH 9.9.

Horizon		I	II	III	IV	V
CHEMICAL ANALYSES						
pH		9.0	10.0	10.0	9.9	9.9
$CaCO_3$ Equiv. (%)		1.06	1.23	5.12	7.38	4.13
Org. C (%)		1.10	0.81	-	-	-
Total N (%)		0.10	0.06	-	-	-
Exchange	H^+	-	-	-	-	-
Analyses	Ca^{++}	-	-	-	-	-
(meq/100 g)	Mg^{++}	-	-	-	-	-
	Na^+	-	-	-	-	-
	K^+	-	-	-	-	-
	TEC	-	-	-	-	-
Soluble	Ca^{++}	3.00	1.50	0.25	0.25	0.12
Salts	Mg^{++}	1.23	1.06	0.82	0.57	0.33
(meq/1)	Na^+	114	339	400	126	67.4
	K^+	0.13	0.10	0.14	0.10	0.08
	CO_3^{--}	-	1.6	53.6	-	-
	HCO_3^-	20.0	68.7	66.1	49.0	24.4
	SO_4^{--}	109	312	294	91.0	53.8
EC (mmhos/cm)		9.0	20	20	10	5.5
PHYSICAL ANALYSES						
Particle	S	66	60	55	66	54
Size	Si	27	25	24	20	25
Analysis (%)	C	7	15	21	14	19
Texture		SL	SL	SCL	SL	SL
Bulk Density (g/cc)		1.79	1.78	1.64	1.94	1.97
% Hygro. M		0.8	1.6	1.6	0.9	1.0

Saline Carbonated Gleyed Regosol

Parent Material: Till
Topography: b
Elevation: 2,100 ft.
Location: SW 1-53-14-4

Drainage Class: Poorly drained
Water Table (depth): 1 ft. (estimated)
Vegetation: Red samphire (*S. rubra*)

Horizon	Depth (in.)	Description
Ahjsaca	0-10	Very dark gray (10 YR 3/1 m) sandy loam; amorphous; very friable; plentiful very fine roots; gradual, wavy boundary; 5 to 10 inches thick; pH 8.4.
Ccasag	10-26	Yellowish brown (10 YR 5/6 m) sandy loam; amorphous; friable; diffuse, wavy boundary; 12 to 18 inches thick; pH 8.3.
Csk	26+	Dark grayish brown (10 YR 4/2 m) loam; amorphous; firm; pH 8.4.

Horizon		Ahjsaca	Ccasag	Csk
CHEMICAL ANALYSES				
pH		8.4	8.3	8.4
$CaCO_3$ Equiv. (%)		7.34	3.55	2.68
Org. C (%)		1.50	-	-
Total N (%)		0.15	-	-
Exchange	H^+	-	-	-
Analysis	Ca^{++}	-	-	-
(meq/100 g)	Mg^{++}	-	-	-
	Na^+	-	-	-
	K^+	-	-	-
	TEC	-	-	-
Soluble	Ca^{++}	18.0	9.0	3.0
Salts	Mg^{++}	108	78.7	14.8
(meq/1)	Na^+	661	456	113
	K^+	1.90	0.92	0.36
	CO_3^{--}	-	-	-
	HCO_3^-	7.76	1.84	2.30
	SO_4^{--}	769	606	132
EC (mmhos/cm)		20	20	11.0
PHYSICAL ANALYSES				
Particle	S	52	53	48
Size	Si	34	30	35
Analysis (%)	C	14	17	17
Texture		SL	SL	L
Bulk Density (g/cc)		1.55	1.92	1.98
% Hygro. M		2.0	1.2	1.2

APPENDIX A-II

Typical horizon sequences for soil subgroups mapped in the study area and listed in the Soil Map legend.

Subgroup Name	Profile Type
Eluviated Black	Ah*, Ae, Bt, Cca, Ck
Carbonated Eluviated Black	Ah, Ae, Btk, Cca, Ck
Gleyed Eluviated Black	Ah, Ae, Btg, Ccag, Ck
Truncated Eluviated Black	Ah (partly eroded), Ae, Bt, Cca, Ck
Rego Black	Ah, AC, Cca, Ck
Saline Rego Black	Ahs, Ccasa, Csk
Carbonated Rego Black	Ahk, Cca, Ck
Saline Carbonated Rego Black	Ahsk, Ccasa, Csk
Saline Gleyed Rego Black	Ahs, Ccasag, Cskg
Carbonated Gleyed Rego Black	Ahk, Ccag, Ckg
Saline Carbonated Gleyed Rego Black	Ahsk, Ccasag, Cskg
Cumulic Rego Black	Ah, Ahk, ACk, Cca, Ck
Solodic Black	Ah, Ae, AB, Bnjt, Ccas, Csk
Black Solonetz	Ah, Ae, Bnt, Ccasa, Csk
Carbonated Black Solonetz	Ahk, Aek, Bntk, Ccasa, Csk
Gleyed Black Solonetz	Ah, Aeg, Bntg, Ccasa
Thin Black Solonetz	Ah (<4" thick), Ae, Bntk, Ccasa, Csk
Carbonated Thin Black Solonetz	Ahk, Aek, Bntk, Ccasa, Csk
Gleyed Thin Black Solonetz	Ah, Aeg, Bntgk, Ccasa, Csk
Carbonated Gleyed Thin Black Solonetz	Ahk, Aegk, Bntgk, Ccasa, Csk

* All the Ah horizons may be Ap horizons.

Subgroup Name	Profile Type
Black Solod	Ah, Ae, AB, Bnt, Ccasa, Csk
Orthic Humic Gleysol	Ah, Bg, Cg or Cgk
Saline Orthic Humic Gleysol	Ahs, Bgs, Cgs
Carbonated Orthic Humic Gleysol	Ahk, Bgk, Cgk
Carbonated Saline Orthic Humic Gleysol	Ahsk, Bgsk, Cgsk
Rego Humic Gleysol	Ah, Cg or Ckg
Saline Rego Humic Gleysol	Ahs, Cskg
Carbonated Rego Humic Gleysol	Ahk, Ccag
Carbonated Saline Rego Humic Gleysol	Ahsk, Ccasag
Humic Eluviated Gleysol	Ah, Ahe, Aeg, Btg, Cg
Low Humic Eluviated Gleysol	Ap, Aeg, Btg, Cg
Saline Carbonated Orthic Regosol	Ahjsaca, Ccasa, Csk
Saline Carbonated Gleyed Regosol	Ahjsaca, Ccasag, Cskg

APPENDIX B

List of Chemical Analyses of Water Samples in the Vegreville Study Area

Note:

S = Spring

F = Flowing well

R = River

* = Deteriorated well, analyses questionable

#66, 68, 71 give analyses of water taken from the Vermilion River during a dry period with low stream-flow.

#149, 150 give analyses of water taken from the Vermilion River after heavy rains with high stream-flow.

Sample No.	Location West of 4th Meridian Lsd.	Sec.	Tp.	R.	Depth of well (ft.)	Water Level (depth ft.)	Temp. °C	pH	EC mmhos/cm	TDS epm	Ca^{++}/Mg^{++}	Ca^{++} epm	%	Mg^{++} epm	%	Na^{+} epm	%	K^{+} epm	%	CO_3^{--} epm	%	HCO_3^{-} epm	%	SO_4^{--} epm	%	Cl^{-} epm	%
1	4	34	52	14	40	20	6.2	7.8	2.6	48.7	1.9	7	28	3.6	14	14	58	0.1	-			7.6	32	16	68	0.1	-
2	4	2	53	14	24	7	3.1	7.5	4.8	102	1.1	8.7	17	8.0	15	35	68	0.2	-			11	22	38	78	0.1	-
3	15	35	52	14	60	12		8.8	1.2	23.4	3.3	0.1	1	0.03	-	12	99	0.02	-	1.0	9	9.6	85	-	-	0.7	6
4	1	1	53	14	305	54		7.9	1.4	25.8	10	0.2	2	0.02	-	13	98	0.02	-			11	87	1.4	11	0.2	2
5	1	1	53	14	80	12		7.5	1.4	28.8	2.8	8.7	59	3.1	21	2.8	19	0.2	1			9.7	69	4.3	31	-	-
6	4	31	52	13	85	15		7.5	2.0	41.3	1.5	11	49	7.5	33	3.9	17	0.2	1			9.4	50	8.8	47	0.5	3
7	1	36	52	14	60	10	4.2	7.7	4.4	86.4	1.0	8.5	18	8.2	18	30	64	0.1	-			8.5	21	31	79	0.1	-
8	1	36	52	14	240	15	8.0	8.7	1.3	20.9	5.0	0.1	1	0.02	-	12	99	0.02	-	3.4	39	4.8	54	-	-	0.6	7
9	15	10	53	14	75	16		7.9	1.4	29.2	2.8	0.2	1	0.07	1	14	98	0.02	-			12	81	2.9	19	0.1	-
10	8	10	53	14	95		5.5	8.9	1.4	24.8	4.0	0.4	3	0.1	1	13	96	0.05	-	2.3	20	6.9	62	1.8	16	0.2	2
11	10	11	53	14	S		9.5	8.9	2.6	41.1	1.5	0.3	1	0.2	1	26	98	0.08	-	3.8	26	7.4	51	3.3	23	-	-
12	1	14	53	14	S			9.2	1.9	35.2	1.5	0.3	2	0.2	1	18	97	0.08	-	1.4	8	11	66	4.2	25	-	-
13	3	12	53	14	135			7.7	1.5	30.5	3.2	4.2	28	1.3	9	9.1	62	0.2	1			11	71	4.5	29	-	-
14	12	1	53	14	60	30	5.5	7.5	1.5	33.1	2.4	9.5	58	3.9	24	2.8	17	0.2	1			9.4	56	7.2	43	0.1	1
15	12	1	53	14	265	30		8.5	1.2	22.8	5.0	0.1	1	0.02	-	12	99	0.02	-	0.7	6	10	94	-	-	-	-
16	8	2	53	13	100	20	5.5	8.0	1.3	25.8	5.0	0.1	-	0.02	-	13	99	0.02	-			11	88	1.5	12	-	-
17	4	7	53	13	80	40		7.5	0.9	16.6	1.8	4.5	55	2.5	30	1.1	13	0.1	1			7.2	86	1.2	14	-	-
18	3	32	52	13	105	30		7.8	1.8	34.9	2.5	3.2	18	1.3	7	13	74	0.1	1			9.7	56	7.5	43	0.1	1
19	3	32	52	13	60	20		7.7	1.8	37.2	1.7	9.5	50	5.7	30	3.7	19	0.2	1			9.2	51	8.8	49	0.6	-
20	8	6	53	13	108	18	7.2	7.7	1.7	37.5	2.9	3.5	19	1.2	6	14	74	0.1	1			12	65	6.6	35	0.1	-
21	8	5	52	13	200	30		8.4	1.4	27.1	3.3	0.1	1	0.03	-	14	99	0.02	-	0.6	5	11	86	1.2	9	0.1	-
22	8	5	52	13	70	18		7.5	2.2	43.9	2.2	6.2	26	2.8	11	15	62	0.2	1			11	56	8.7	44	0.1	-
24	5	3	53	13	60	50		7.7	1.3	27.2	1.9	8	55	4.3	29	2.2	15	0.1	1			9	72	3.5	28	0.1	-
25	4	10	53	13	80	35		7.4	1.5	29.5	1.6	8	51	4.9	31	2.6	17	0.1	1			8.1	58	5.8	40	0.3	2
26	1	14	53	14	S			8.1	1.7	32.0	2.8	0.2	1	0.07	-	16	99	0.02	-	0.2	1	12	77	3.5	22	-	-
27	4	24	53	14	F		6.5	8.2	1.7	31.6	6.7	0.2	1	0.03	-	17	99	0.05	-	0.3	2	12	84	2.0	14	-	-
28	8	23	53	14	*	10		7.9	4.7	93.7	1.2	4.5	9	3.8	8	39	83	0.2	-			32	70	14	30	0.2	-
29	13	19	53	13	60	11		7.7	1.1	23.8	1.4	6.0	48	4.3	34	2.2	17	0.1	1			8.8	79	2.4	21	-	-
30	16	24	53	14	30	11	5.5	7.8	1.6	34	1.3	9.0	50	7.0	39	2.0	11	0.1	-			11	70	4.2	26	0.7	4
31	1	24	53	14	60	20	5.5	7.4	2.2	49.3	1.6	14	53	8.8	33	3.5	13	0.3	1			9.5	42	13	57	0.2	1
32	7	24	53	14	S			7.6	1.8	36.3	1.8	7.2	37	4	21	7.8	40	0.4	2			10	59	6.9	41	-	-
33	13	18	53	13	50	30		7.7	1.5	33.3	2.0	8.8	51	4.5	26	3.8	22	0.2	1			9.2	58	6.8	42	-	-
34	12	15	53	13	220		8.0	8.2	1.4	27.5	1.0	0.2	2	0.2	2	13	96	0.08	-	0.3	2	13	93	0.6	4	0.1	-
35	7	13	53	14	40			7.6	1.2	22.8	2.3	5.5	46	2.4	20	3.9	32	0.2	2			8.4	78	2.2	20	0.2	2
36	7	13	53	14	40			7.4	1.1	22.2	2.3	5.2	47	2.3	21	3.3	30	0.2	2			8.8	78	2.2	20	0.2	2
37	14	7	53	13	80	30	6.8	7.7	0.6	12.3	2.0	3.5	53	1.7	26	1.3	20	0.08	1			5.4	96	0.2	4	0.1	1
38	16	7	53	13	151	140	7.5	7.8	1.4	29.2	2.0	8.2	55	4.2	28	2.2	15	0.2	1			11	76	3.4	24	0	-
39	16	7	53	13	45	35	3.9	7.6	1.0	19.2	1.9	6.2	62	3.3	33	0.3	3	0.2	2			0.8	87	1.1	12	0.06	1
40	13	8	53	13				7.6	1.7	31.6	1.3	9.2	52	7.1	40	1.3	7	0.2	1			11	80	2.6	19	0.2	1

(continued)

Sample No.	Location West of 4th Meridian Lsd.	Sec.	Tp.	R.	Depth of well (ft.)	Water Level (depth ft.)	Temp. °C	pH	EC mmhos/cm	TDS epm	Ca^{++}/Mg^{++}	Ca^{++} epm	%	Mg^{++} epm	%	Na^+ epm	%	K^+ epm	%	CO_3^{--} epm	%	HCO_3^- epm	%	SO_4^{--} epm	%	Cl^- epm	%
41	16	8	53	13	25	15	3.7	7.7	1.0	20.2	1.7	6.0	56	3.5	33	1.1	10	0.1	1			8.0	84	1.5	16	0.03	-
42	16	8	53	13	25	12	2.7	7.6	1.0	18.9	1.1	4.5	45	4.0	40	1.4	14	0.1	1			7.8	88	1.0	11	0.08	1
43	15	9	53	13	52	12	5.5	7.6	2.0	43.1	2.2	8.2	37	3.8	17	10	45	0.2	1			12	58	8.9	42	-	-
44	15	9	53	13	S		5.5	7.7	1.9	41.3	2.3	7.0	33	3.2	15	11	51	0.2	1			11	55	8.9	45	-	-
45	16	34	53	14	24	20		7.5	2.4	47.2	1.9	7.8	32	4.1	17	12	50	0.2	1			9.1	39	14	61	0.02	-
46	16	34	53	14	45	21	5.5	7.8	2.6	51.4	2.3	8.0	30	3.5	13	15	56	0.2	1			9.7	39	15	60	0.01	-
47	15	36	53	14	50	20	5.5	7.7	2.5	43.2	2.7	0.8	4	0.3	1	19	95	0.1	-			11	48	12	52	0.01	-
48	1	36	53	14	54	30	5.4	7.5	1.5	32.9	1.8	8.2	51	4.5	28	3.2	20	0.3	2			11	66	5.6	34	0.06	-
49	13	30	53	13	31	26	3.9	7.5	1.4	28.6	1.9	7.5	51	4.0	27	3.1	21	0.2	1			9.3	67	4.5	33	0.03	-
50	13	30	53	13	22	12	3.8	7.6	1.3	27.6	2.3	6.8	50	3.0	22	3.7	27	0.2	1			9.8	70	4.1	29	-	-
51	14	20	53	13	50	25	5.9	7.5	1.3	27.2	1.4	7.8	53	5.4	37	1.3	9	0.1	1			9.3	75	3.2	25	0.06	-
52	14	20	53	13	60	40	4.9	7.4	1.8	36.3	1.4	9.2	49	6.6	35	2.6	14	0.2	1			12	68	5.6	32	0.08	-
53	15	29	53	13	50	40		7.5	1.8	37.0	1.9	7.0	39	3.7	21	7.0	39	0.2	1			11	58	8.0	42	0.14	-
54	13	32	53	13	46	20	4.9	7.2	2.3	42.2	2.0	9.8	40	4.9	20	9.6	39	0.2	1			11	63	6.6	37	0.08	-
55	9	28	53	13	45	30	3.7	7.5	1.7	32.5	1.3	8.5	47	6.7	37	2.9	16	0.1	-			10	70	4.2	29	0.11	1
56	9	28	53	13	50	20		7.7		21.8	2.1	6.2	56	3.0	27	1.7	15	0.2	2			8.6	80	2.1	20	0.3	-
57	16	21	53	13	50	30		7.4	1.6	32.5	1.7	9.2	52	5.5	31	2.9	16	0.2	1			10	68	4.7	32	0.03	-
58	13	9	53	13	60	40	5.0	7.4	1.9	40.8	1.9	11.0	49	5.8	26	5.3	24	0.2	1			9.2	50	9.2	50	0.06	-
59	9	17	53	13	50			7.6	1.6	34.5	1.5	8.5	48	5.8	32	3.6	20	0.1	-			8.9	54	7.6	46	-	-
60	1	7	53	13	52	40	5.0	7.6	1.5	32.6	1.4	8.8	52	6.5	39	1.3	8	0.2	1			12	76	3.8	24	-	-
61	4	8	53	13			5.9	7.5	1.7	37.8	1.9	10.5	55	5.5	29	3.0	16	0.2	1			11	59	7.6	41	-	-
62	16	36	52	14	40	10		7.6	2.2	43.0	1.8	11.5	49	6.2	26	5.5	24	0.2	1			11	57	8.5	43	0.10	-
63	16	27	52	14	300			7.8	5.0	90.5	1.2	11.2	21	9.0	17	33	62	0.2	-			10	27	27	73	0.06	-
64	16	27	52	14	65			8.3	1.2	23.5	5.0	0.1	1	0.02	-	12	99	0	-	0.4	4	11	96	0	-	-	-
65	5	35	52	14	130		5.0	8.1	2.9	47.5	1.6	1.6	6	1.0	4	23	90	0.1	-			12	55	9.8	45	0.03	-
66	16	34	53	14	R			7.2	1.1	16.3	1.5	1.2	16	0.8	11	5.1	69	0.3	4			6.2	65	3.2	34	0.08	1
67	5	35	53	14	20	10		7.9	3.4	58.7	2.0	4.4	14	2.2	7	24	79	0.1	-			10	36	18	64	-	-
68	15	23	53	14	R			7.7	1.2	20.5	1.5	3.1	29	2.0	19	5.4	50	0.2	2			6.8	69	3.0	31	0.03	-
69	15	13	53	14	S			7.8	4.2	70.2	1.7	1.2	3	0.7	2	39	95	0.1	-			20	68	9.2	32	-	-
70	2	15	53	14	80	40		7.9	2.0	40.5	1.9	8.8	40	4.5	20	8.5	39	0.2	1			6.9	36	12	64	0.02	-
71	9	9	53	14	R			7.5	0.6	16.8	1.4	4.2	39	2.9	27	3.3	31	0.3	3			4.2	69	1.8	20	0.06	1
72	16	32	52	13	60			7.6	1.3	26.0	1.9	7.2	54	3.8	29	2.1	16	0.1	1			9	70	3.8	30	-	-
73	13	33	52	13	42	10		7.3	2.6	54.4	1.4	14.2	48	10.4	35	4.4	15	0.3	1			12	49	13	51	0.08	-
74	13	33	52	13	32	10		7.6	1.2	25.2	1.8	6.8	55	3.8	31	1.6	13	0.1	1			8.8	68	4.1	32	-	-
75	4	33	52	13	50	25		7.4	1.6	32.9	1.5	9.2	55	6.0	36	1.4	8	0.2	1			9	56	7.1	44	-	-
76	12	15	53	13	75	55		7.6	1.2	24.0	1.4	6.0	46	4.33	33	2.6	20	0.13	1			7.39	67	3.06	28	0.55	5
77	12	15	53	13	250	60		9.9	1.4	27.3	3.3	0.2	1	0.06	-	13.0	99	0.07	-	5.2	37	7.16	51	1.12	8	0.50	4
78	12	27	53	13	67	30	6.2	7.3	1.3	27.4	2.3	7.5	56	3.17	24	2.6	19	0.17	1			9.28	67	4.62	33	0.03	-
79	12	3	54	13	53	20	4.4	7.2	1.7	33.7	2.3	6.8	36	2.92	16	8.7	47	2.29	1			10.3	68	4.75	32	0.01	-
80	4	10	54	13	175	50		8.4	1.5	29.0	3.3	0.1	1	0.03	-	13.9	99	0.04	-	0.60	4	12.6	84	-	-	1.75	12

(continued)

Sample No.	Location West of 4th Meridian Lsd.	Sec.	Tp.	R.	Depth of well (ft.)	Water Level (depth ft.)	Temp. °C	pH	EC mmhos/cm	TDS epm	Ca^{++}/Mg^{++}	Ca^{++} epm	%	Mg^{++} epm	%	Na^{+} epm	%	K^{+} epm	%	CO_3^{--} epm	%	HCO_3^{-} epm	%	SO_4^{--} epm	%	Cl^{-} epm	%
81	12	10	54	13	48		4.7	7.1	2.2	39.2	2.0	12.5	59	6.25	30	2.2	10	0.25	1			9.56	53	6.75	37	1.72	10
82	1	30	53	13	70	40	5.1	7.3	1.2	26.2	1.9	7.8	57	4.17	30	1.7	12	0.20	1			9.24	75	2.5	20	0.62	5
83	1	31	53	13	44	32	5.0	7.5	2.1	52.0	1.1	10.8	41	10.0	38	5.2	20	0.24	1			9.16	36	16.5	64	0.15	-
84	16	31	53	13	60	30	5.0	7.2	1.8	43.2	1.7	10.2	47	6.08	28	5.2	24	0.28	1			10.2	47	11.2	53	0.07	-
85	3	9	54	13	60	38	5.0	7.5	1.3	27.6	2.1	5.2	39	2.5	18	5.6	41	0.27	2			9.64	69	4.0	28	0.44	3
86	12	9	54	13		F		8.0	3.0	63.0	1.7	0.68	2	0.4	1	33.0	97	-	-			25.6	89	3.25	11	0.12	-
87	1	3	54	13	90	45		7.4	1.6	37.6	1.4	10.0	51	7.33	37	2.2	11	0.26	1			9.92	56	7.5	42	0.35	2
88	1	2	54	13			5.2	7.3	2.2	43.7	1.0	10.8	45	11.2	47	1.7	7	0.19	1			11.3	57	5.88	30	2.6	13
89	2	26	53	13	85	50		7.4	2.4	53.7	0.9	9.0	31	9.6	33	10	35	0.23	1			12.2	49	11.8	48	0.84	3
90	4	26	53	13				7.5	1.7	38.0	1.8	5.75	30	3.17	16	10.4	53	0.17	1			10.7	58	7.75	42	0.05	-
91	1	34	53	13	70	35	4.6	7.4	1.8	41.4	1.4	10.8	51	7.92	38	2.2	10	0.23	1			11.6	58	7.75	38	0.90	4
92	13	23	53	13	270	80		8.5	1.4	29.3	3.3	0.1	1	0.03	-	14.0	99	0.04	-	0.76	5	13.9	92	-	-	0.48	3
93	13	23	53	13	45	20		7.4	2.2	48.3	1.7	7.0	29	4.17	17	13.0	53	0.17	1			10.4	44	13.5	56	0.03	-
94	12	14	53	13	85			7.2	2.2	51.9	1.4	13.2	49	9.17	34	4.4	16	0.19	1			10.8	43	13.8	56	0.35	1
95	4	2	54	14	43	32		7.5	3.0	64.8	2.6	7.0	21	2.67	8	23.4	70	0.17	1			12.1	38	18.9	60	0.54	2
96	4	2	54	14	28	7		7.3	1.6	33.2	2.4	8.0	45	3.33	19	6.1	35	0.12	1			9.03	58	5.88	38	0.70	4
97	13	35	54	14	56	40		7.8	2.4	48.4	2.7	2.7	11	1.0	4	20.9	85	0.12	-			11.9	50	11.6	49	0.20	1
98	12	2	54	14	65	45		7.4	3.4	69.5	2.2	9.0	26	4.0	12	21.7	62	0.19	-			8.9	27	25.6	73	0.10	-
99	12	2	54	14	65	30		7.7	2.8	55.2	2.6	5.0	18	1.88	6	21.7	76	0.12	-			10.8	41	15.6	59	0.09	-
100	1	10	54	14	65	45	5.8	7.5	2.4	50.0	2.5	7.2	29	2.92	12	14.3	58	0.25	1			10.3	41	15.0	59	0.04	-
101	1	10	54	14	15	5		7.5	1.9	43.7	1.1	6.8	30	6.25	28	9.6	42	0.13	-			13.0	62	7.39	35	0.53	3
102	12	1	54	14	50	35		7.4	1.0	21.5	2.4	2.8	25	1.17	11	6.9	63	0.17	1			9.0	86	1.25	12	0.22	2
103	2	4	54	13	30	18	3.1	7.2	2.0	41.4	1.7	9.5	43	5.67	26	6.5	30	0.19	1			12.6	64	6.19	32	0.72	4
104	13	22	53	13	60	35	5.6	7.6	1.1	23.5	1.9	6.5	53	3.33	27	2.2	18	0.27	2			7.67	69	3.06	27	0.45	4
105	4	35	53	13	7	F		7.4	1.7	33.8	1.8	5.2	31	2.92	17	8.7	51	0.17	1			9.1	54	7.75	46	0.01	-
106	2	15	53	13			5.4	7.5	2.4	50.5	1.1	10.5	40	9.17	35	6.5	25	0.24	1			10.5	44	12.9	53	0.70	3
107	1	10	53	13			5.4	7.6	2.1	39.9	2.3	2.3	12	1.0	-	16.1	82	0.15	1			12.1	60	8.19	40	0.03	-
108	16	3	53	13	40	15		7.5	1.2	20.8	1.5	6.2	52	4.0	33	1.7	14	0.10	1			7.08	80	1.0	11	0.76	9
109	12	34	52	13	240	15		7.4	1.4	29.4	2.8	4.2	29	1.5	10	8.7	59	0.25	2			10.0	68	4.75	32	0.03	-
110	12	34	52	13	60	25		7.5	1.5	47.0	1.2	8.2	50	6.67	41	1.3	8	0.13	1			8.39	27	21.3	70	0.98	3
111	1	3	54	14	40	30	4.5	7.5	2.1	35.0	2.3	4.8	22	2.08	9	14.8	68	0.24	1			9.0	69	3.12	24	0.93	7
112	14	26	53	14	40	31	4.8	7.4	1.8	40.4	2.0	7.0	34	3.58	18	9.6	47	0.23	1			7.75	39	11.9	59	0.35	2
113	14	26	53	14	25	8		7.3	1.2	36.8	1.5	4.0	27	2.67	18	7.8	54	0.17	1			9.75	44	11.9	54	0.53	2
114	5	23	53	14	70	20	5.8	8.3	1.4	32.9	1.2	0.28	2	0.23	1	15.2	97	0.05	-	0.28	1	14.2	83	1.88	11	0.81	5
115	1	22	53	14	140	40	5.4	8.7	1.5	32.0	4.7	0.14	1	0.03	-	16.5	99	0.05	-	0.84	6	13.9	91	0.31	2	0.20	1
116	2	15	53	14	165	40		8.8	1.4	29.7	4.7	0.14	1	0.03	-	15.2	99	0.05	-	1.12	8	11.8	82	1.12	8	0.26	2
117	16	9	53	14	180	10		8.4	1.5	32.6	5.0	0.10	1	0.02	-	15.2	99	0.05	-	0.44	3	13.0	75	1.38	8	2.45	14
118	8	9	53	14	100	22	4.7	8.1	1.5	33.8	5.0	0.20	1	0.04	-	16.5	99	0.06	-			15.1	89	1.62	10	0.26	1
119	8	9	53	14	50	12		7.7	1.9	37.3	2.0	5.0	25	2.5	12	12.6	62	0.30	1			6.0	36	10.6	63	0.27	1
120	1	4	53	14	40	15	5.5	7.3	5.0	12.6	1.6	26.0	37	16.7	24	26.9	39	0.32	-			8.8	16	45.9	82	1.01	2

(Continued)

Sample No.	Location West of 4th Meridian Lsd.	Sec.	Tp.	R.	Depth of well (ft.)	Water Level (depth ft.)	Temp. °C	pH	EC mmhos/cm	TDS epm	Ca^{++}/Mg^{++}	Ca^{++} epm	%	Mg^{++} epm	%	Na^{+} epm	%	K^{+} epm	%	CO_3^{--} epm	%	HCO_3^{-} epm	%	SO_4^{--} epm	%	Cl^{-} epm	%
121	16	33	52	14	88	25		7.5	1.8	37.1	2.1	8.75	45	4.17	21	6.5	33	0.26	1			8.2	47	8.75	50	0.45	3
122	3	28	52	14	96			8.5	1.5	30.6	6.0	0.12	1	0.02	-	14.8	99	0.05	-	0.72	5	12.1	77	-	-	2.79	18
123	8	8	53	14	20	10		7.4	2.8	64.1	1.5	11.8	36	7.71	23	13.5	40	0.25	1			7.6	25	22.2	72	1.04	3
124	14	9	53	14	154			8.3	1.5	31.5	5.5	0.11	1	0.02	-	15.6	99	0.05	-	0.28	2	12.3	78	-	-	3.15	20
125	1	17	53	14	26	12		7.3	1.8	40.3	1.5	7.75	37	5.0	24	7.8	38	0.20	1			8.5	43	10.7	55	0.39	2
126	1	17	53	14	190	80		8.6	1.5	32.6	3.7	0.11	1	0.03	-	16.1	99	0.05	-	1.04	6	13.8	85	-	-	1.49	9
127	1	20	53	14	157	17		8.2	1.5	34.8	3.5	0.35	2	0.10	1	16.5	97	0.08	-	0.2	1	17.2	97	-	-	0.32	2
128	12	21	53	14	22	7		7.3	2.4	46.8	2.4	16.2	60	6.67	24	4.3	16	0.11	-			8.75	45	8.0	41	2.73	14
129	16	20	53	14	28	15		7.8	1.6	38.6	1.5	8.5	43	5.67	28	5.6	28	0.16	1			8.56	46	10.0	54	0.09	-
130	1	28	53	14	50	20		7.3	2.6	70.5	1.6	19.8	53	12.1	32	5.2	14	0.22	1			8.20	25	23.7	71	1.29	4
131	9	16	53	14	136	20		8.3	1.5	31.6	1.3	0.32	2	0.25	2	15.2	96	0.05	-	0.32	2	14.2	90	1.0	6	0.25	2
132	1	4	54	14	30			7.3	1.3	26.1	2.3	8.0	55	3.5	24	3.0	20	0.16	1			9.5	83	1.0	9	0.90	8
133	14	33	53	14	144	22		7.9	1.1	24.0	3.1	0.55	5	0.18	1	11.3	93	0.07	1			9.95	84	1.75	15	0.17	1
134	14	33	53	14	44	28		7.5	2.3	52.4	0.7	10.2	37	14.6	54	2.2	8	0.20	1			19.4	77	2.25	9	3.6	14
135	12	3	54	14	60	15		7.5	1.0	21.1	1.6	5.5	52	3.33	31	1.7	16	0.15	1			7.75	75	2.62	25	0.01	-
136	12	3	54	14				7.8	1.7	38.4	1.8	8.25	41	4.58	22	7.4	36	0.17	1			10.9	60	6.94	39	0.21	1
137	1	27	52	14	45	20		8.1	2.5	51.0	4.1	1.35	5	0.33	1	26.1	94	0.12	-			9.95	43	12.9	56	0.25	1
138	4	26	52	14	35			7.8	2.4	49.1	3.6	1.20	5	0.33	1	25.2	94	0.12	-			12.4	56	9.69	44	0.12	-
139	15	23	52	14	180	80		8.1	1.1	24.0	4.5	0.09	1	0.02	-	12.2	99	0.05	-			11.4	98	-	-	0.21	2
140	8	25	52	14	60	30	4.5	7.4	1.6	37.7	2.9	9.75	51	3.33	17	5.6	30	0.31	2			10.2	55	8.5	45	0.03	-
141	16	19	52	13	180	10		8.2	1.2	26.1	4.5	0.09	1	0.02	-	13.0	99	0.04	-	0.32	3	12.5	96	-	-	0.17	1
142	14	20	52	13	47	20		7.9	0.8	18.2	1.9	5.25	56	2.7	29	1.3	14	0.10	1			7.28	82	1.31	15	0.28	3
143	8	19	52	13	42	18	4.5	7.5	1.9	42.6	2.4	10.2	45	4.17	19	7.8	35	0.23	1			9.28	46	10.9	54	0.01	-
144	2	29	52	13	125	40	5.4	8.1	1.2	19.6	2.4	1.10	8	0.46	3	12.2	88	0.12	1			0.97	17	4.75	83	0.01	-
145	12	27	52	13	36	10		8.0	1.8	48.5	2.6	2.8	14	1.08	6	15.6	79	0.20	1			11.7	61	7.38	39	0.01	-
146	12	27	52	13	60	12		7.6	3.6	80.5	0.9	9.5	22	10.4	24	22.6	54	0.23	-			13.2	35	23.1	61	1.46	4
147	1	14	53	13	45		5.4	7.9	0.7	16.0	2.2	3.75	45	1.67	20	2.6	32	0.26	3			6.9	90	0.75	10	0.03	-
148	8	25	53	14				7.6	1.3	30.3	3.0	8.25	54	2.75	18	3.9	26	0.33	2			9.4	62	5.62	38	0.03	-
149	16	34	53	14	R			6.9	0.26	7.27	1.3	0.73	20	0.57	15	2.2	59	0.24	6			2.2	62	1.31	38	0.02	-
150	12	10	53	14	R			6.9	0.30	6.85	1.7	0.73	20	0.43	12	2.2	62	0.22	6			2.2	67	1.06	33	0.01	-

APPENDIX C

Description of Surficial Groundwater Features

Site No.	Description
1	Filled in shallow flowing well seepages, differentially eroded surfaces.
2	Seepages, differentially eroded surfaces.
3	Seepages, phreatophytes.
4	Soaphole, phreatophytes.
5	Area of seepages, soapholes, differentially eroded surfaces.
6	Indefinite depression.
7 to 11	Fast recharge sloughs.
12 and 13	Slow recharge sloughs.
14	Discharge slough (lake).
15	Indefinite slough.
16	Discharge slough (lake).
17	Indefinite sloughs.
18 and 19	Fast recharge sloughs.
20	Drainageway, halophytes, phreatophytes.
21	Fast recharge slough.
22 and 23	Discharge sloughs.
24	Fast recharge slough.
25	Discharge slough.
26	Indefinite slough.
27	Burnt crop.
28	Indefinite slough.
29	Salt precipitates, permanently wet ditch.
30	Flowing well, phreatophytes.
31	Drainageway, spring, seepages, halophytes, phreatophytes.
32	Indefinite slough.

Site No.	Description
33	Discharge slough.
34	Discharge slough, fenced around.
35	Recharge slough (Plate VII).
36 and 37	Discharge slough.
38 and 39	Fast recharge sloughs.
40	Slow recharge slough.
41	Discharge slough (lake).
42	Dry depression.
43 and 44	Slow recharge sloughs.
45	Seepage, phreatophytes.
46	Seepage, salt precipitates, phreatophytes.
47	Discharge slough.
48	Spring, phreatophytes.
49	Seepage, differentially eroded surfaces.
50	Soaphole.
51	Seepage.
52	Salt precipitates, burnt crop.
53	Indefinite meadow.
54 and 55	Fast recharge sloughs.
56	Indefinite slough, filled in well, seepage.
57	Seepage in gully.
58	Fast recharge slough.
59	Dry depression.
60	Slow recharge slough.
61	Indefinite slough.
62	Fast recharge slough.
63	Indefinite slough.
64	Slow recharge slough.
65	Indefinite slough.
66	Fast recharge slough.
67	Discharge slough.

Site No.	Description
68 and 69	Indefinite slough.
70	Slow recharge slough.
71	Fast recharge slough.
72 to 74	Indefinite sloughs.
75 and 76	Discharge sloughs.
77	Slow recharge slough.
78	Dry depression.
79	Spring, phreatophytes.
80	Discharge slough.
81	Fast recharge slough.
82	Discharge slough.
83	Fast recharge slough.
84	Slow recharge slough.
85	Fast recharge slough.
86	Slow recharge slough.
87	Indefinite slough.
88	Fast recharge slough.
89 to 94	Slow recharge sloughs.
95	Indefinite slough.
96 and 97	Slow recharge sloughs.
98	Discharge slough.
99 and 100	Indefinite sloughs.
101	Drainageway, salt precipitates, halophytes, phreatophytes.
102	Indefinite slough.
103	Fast recharge slough.
104	Drainageway, salt precipitates, halophytes.
105	Salt precipitates, burnt crop, seepage.
106	Discharge slough.
107 and 108	Seepage, differentially eroded surfaces.
109	Fast recharge slough.

Site No.	Description
110	Salt precipitate.
111	Fast recharge slough.
112	Drainageway, salt precipitates, halophytes, phreatophytes.
113	Slow recharge slough.
114	Fast recharge slough.
115	Drainageway, salt precipitates, halophytes.
116	Spring, microhummocky ground surface.
117	Spring, eroded gully.
118	Spring, eroded gully, phreatophytic, salt precipitates (Plate I).
119	Seepage, eroded gully, salt precipitates.
120	Well that was flowing about 30 years ago, local report.
121	Discharge depression, salt precipitates.

APPENDIX D

Microbiological Investigations

Introduction

A microbial examination of water and mud samples from two springs in the study area was carried out as part of a course (Soil Science 530) project. The main objective was to obtain some qualitative and quantitative information on the microbiology of groundwater.

Methods

Water and mud samples were collected aseptically from two springs located at sites 79 and 118 (Map 7) in November, 1970.

Sample dilutions were spread on plate count agar and incubated at room temperature in order to obtain aerobic and anaerobic plate counts.

"Most probable number" (MPN) studies were carried out on the following processes: nitrification, using Medium A broth[1]; denitrification, using Difco penassay broth[1] + 10 per cent KNO_3; iron reduction, using B_{10} broth[1] + 10 minute pasteurization; and sulfate reduction, using Butlin's broth[1].

Isolates were prepared from the plate count agars, iron reducers, and sulfate reducers.

[1] Medium commonly used in Soil Microbiology Laboratory, Department of Soil Science.

Results and Discussion

Tables 7 and 8 show the numbers of organisms per ml of sample for each of the determinations. A ml of mud sample is actually a ml of mud-water mixture.

The results (Tables 7 and 8) indicate that the mud samples contain a much greater number of organisms per ml than the water samples. It is also evident that the overall microbial population is greatest in the mud at site 118. This may be related to water chemistry (site 79 = sample 44, Appendix B; and site 118 = sample 12, Appendix B). The chemical analysis of water indicates that the amount of TDS is similar at both sites. However, pH = 7.2 at site 79 and pH = 9.2 at site 118. The relative concentrations (epm) of $Ca^{++} + Mg^{++}$ and Na^{+} are approximately equal at site 79 but Na^{+} is dominant at site 118.

Upon isolation of the sulfate reducers, it was found that what appeared to be reduction by Desulfovibrio sp. was actually a symbiotic reduction of iron and sulphite by other organisms. One organism that is responsible for this reduction is apparently the "Bacillus type 92" which was first isolated by Panter (1968) from a slough bottom.

Characteristics of Bacillus Type 92 are:

(1) it reduces Fe^{+++} to Fe^{++} using Fe^{+++} as terminal electron acceptor,

(2) it reduces SO_3^{--} not SO_4^{--} to S^{--} using SO_3^{--} as the terminal electron acceptor.

Two methods were successful in isolating Bacillus Type 92:

(1) Anaerobic plating of mud dilutions on plate count agar and picking

Table 7. Numbers of Organisms on Plate Count Agars/ml Sample

	Aerobic	Anaerobic
79 water	2,000	800
118 water	3,300	750
79 mud	200,000	20,000
118 mud	7,500,000	670,000

Table 8. Numbers of Organisms by MPN Studies/ml Sample

	Nitrifiers	Denitrifiers	Iron Reducers	Sulfate Reducers
79 water	50	10	10	160
118 water	none	10	25	160
79 mud	15,000	20,000	17,000	8,000
118 mud	2,400	50,000	35,000	1,000,000 +

of the colonies directly, and

(2) Transfers were made in Butlin's broth from MPN sulfate reducers until rapid reduction occurred. The sulfate reducers were then tubed in Butlin's + K_2SO_3 medium. Black single colonies were picked. These proved to be pure cultures of Bacillus 92.

Nine isolates of Bacillus 92 were placed in stock. Preliminary observations indicate that there is variation among the nine. Testing of these pure cultures indicates:

(1) all 9 form typical colony on B_{10} agar,

(2) all 9 reduce Fe^{+++} in B_{10} to vivianite, and

(3) all 9 reduce SO_3^{--} to S^{--} in Butlin's broth.

Clostridia were also isolated by anaerobic plate. These were a mixture of SO_3^{--} reducers and SO_3^{--} non-reducers.

Cytophaga sp. and *Chromobacterium violaceum* were isolated by aerobic plate.

Conclusions

The results indicate that samples should be collected from the mud as well as from the water for microbial analyses of natural waters.

This is apparently the second time that Bacillus 92 has been isolated. Panter (1968) originally isolated this species from a slough bottom sample but was unsuccessful in obtaining isolates from well-drained soils. Therefore, it appears that the habitat of Bacillus 92 is restricted to a wet environment.

Since a large number of sulfate reducers occur in the samples it is possible that these organisms may decrease the concentration of SO_4^{--} in the groundwater. Further examination is required to establish whether these organisms are active at greater depths.

APPENDIX E

Piezometers

Introduction

Five nests of piezometers were installed in the area on September, 1970, by the Soils, Geology and Groundwater Branch, Water Resources Division, Alberta Department of Agriculture.

The main objective was to obtain measurements of the groundwater potential in order to construct a flow diagram that would show the direction of groundwater movement from the central upland to the Vermilion River. This measured flow distribution could then be compared to one predicted from field mapping.

Construction and Arrangement of Piezometer Nests

A shallow observation well and three deep piezometers were installed at each nest. A rotary drilling rig was used and the piezometers were installed according to a procedure similar to that outlined by Hall (Meyboom *et al.*, 1967, p. 7). However, the piezometers were not developed; they were merely flushed.

The locations of the nests are illustrated on Map 2 and the depths of each piezometer are shown in a cross-section (Figure 15).

Water levels were measured at least once a month from the time of installation until April, 1971.

Results and Discussion

Measurements indicate that water levels in most of the piezometers have not stabilized after 7 months.

The equipotential lines and flow lines that represent the measured values are sketched in Figure 15.

Groundwater recharge is indicated in the upland region. Lateral and slight downward movement but no extensive upward movement is indicated at the lower elevation. These observations do not completely support the field observations which indicated definite discharge conditions at the lower elevations.

Since the water levels in the piezometers did not stabilize quickly, one may assume that the piezometers are not functioning properly. As a result, one cannot be confident that the potential measurements obtained thus far represent the actual groundwater potential.

The slow stabilization of water levels is most likely due to the lack of development of the piezometers.

It is recommended that the piezometers be developed in the future. The potential measurements may then be used to construct a flow diagram which may be compared to the one predicted from field mapping.

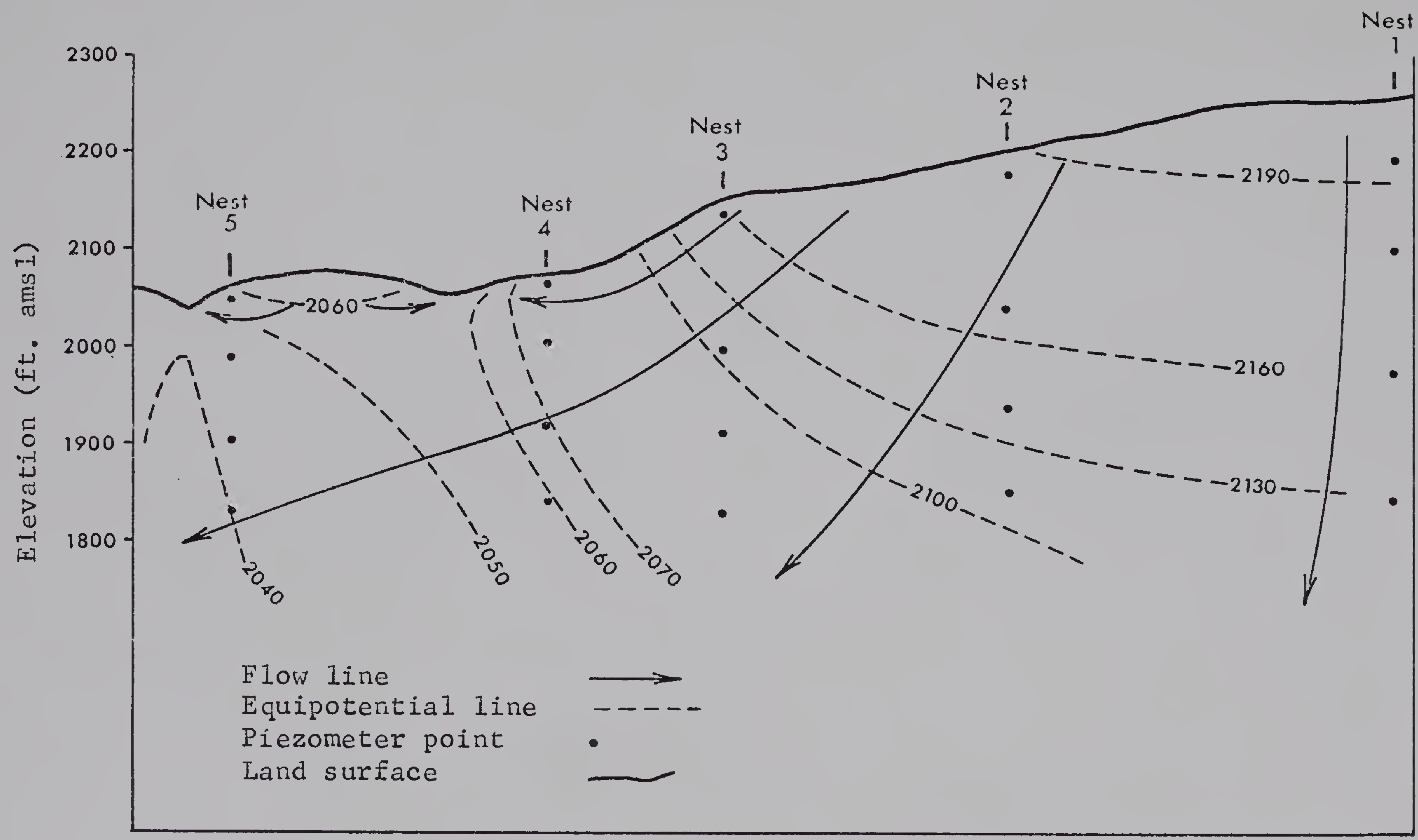
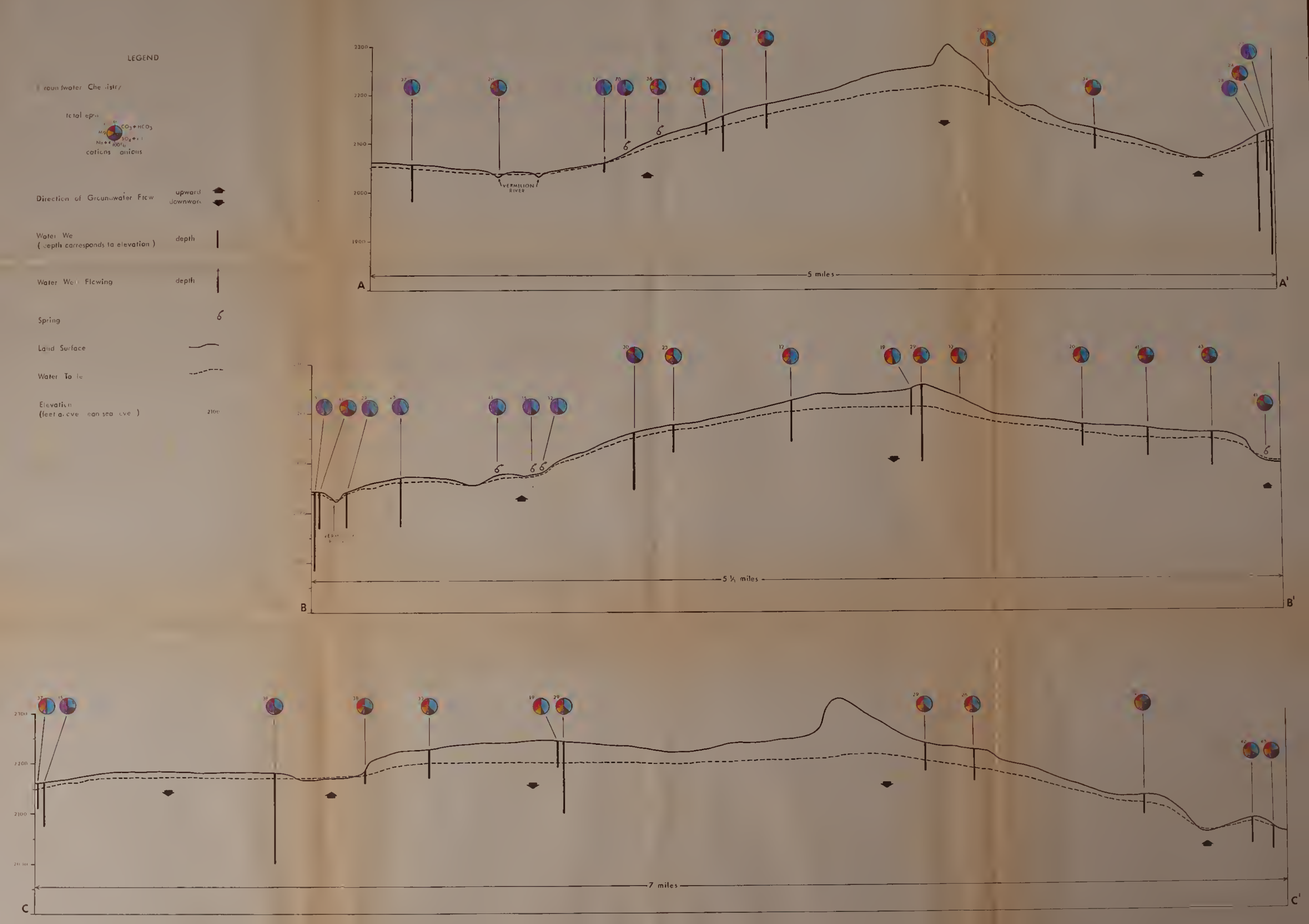


Figure 15. Groundwater flow paths as determined from piezometric measurements.

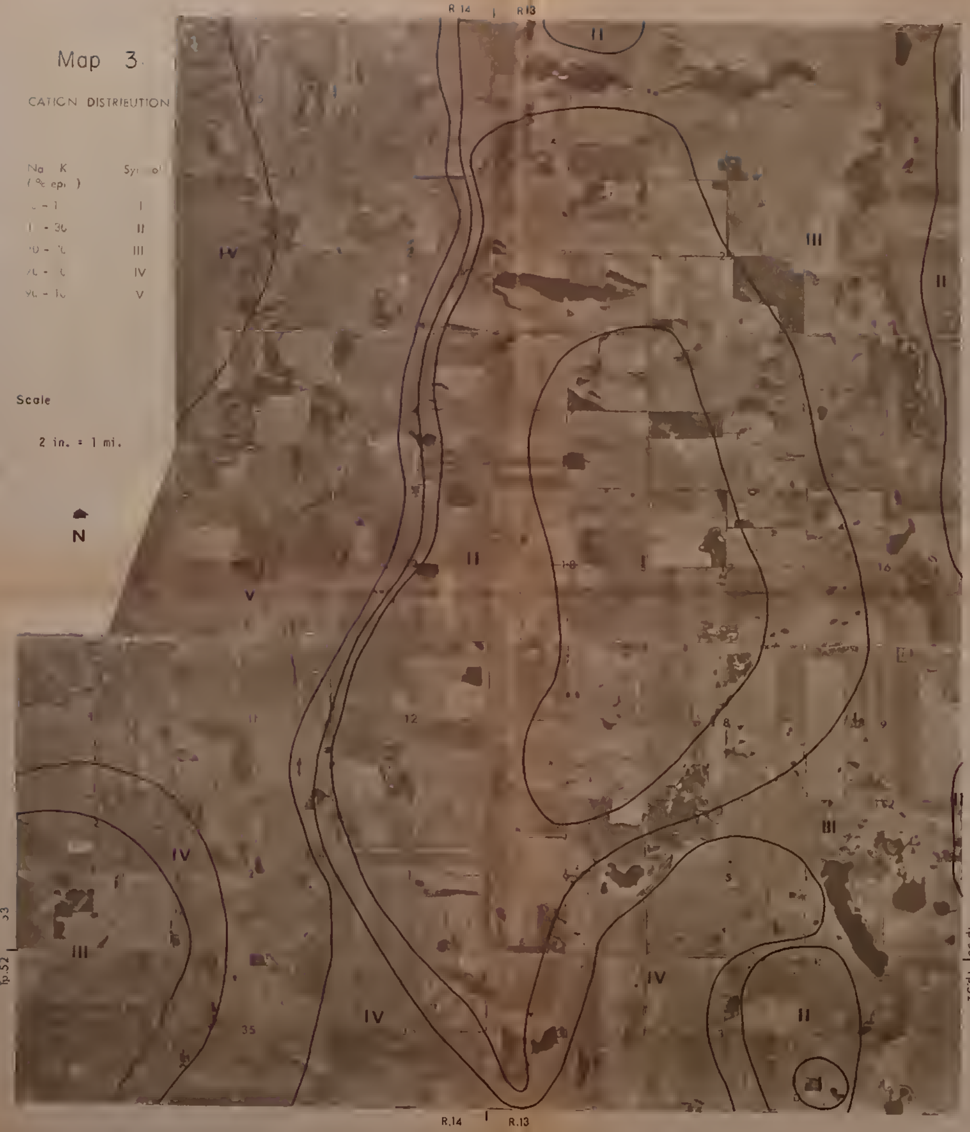
HYDROLOGICAL PROFILES

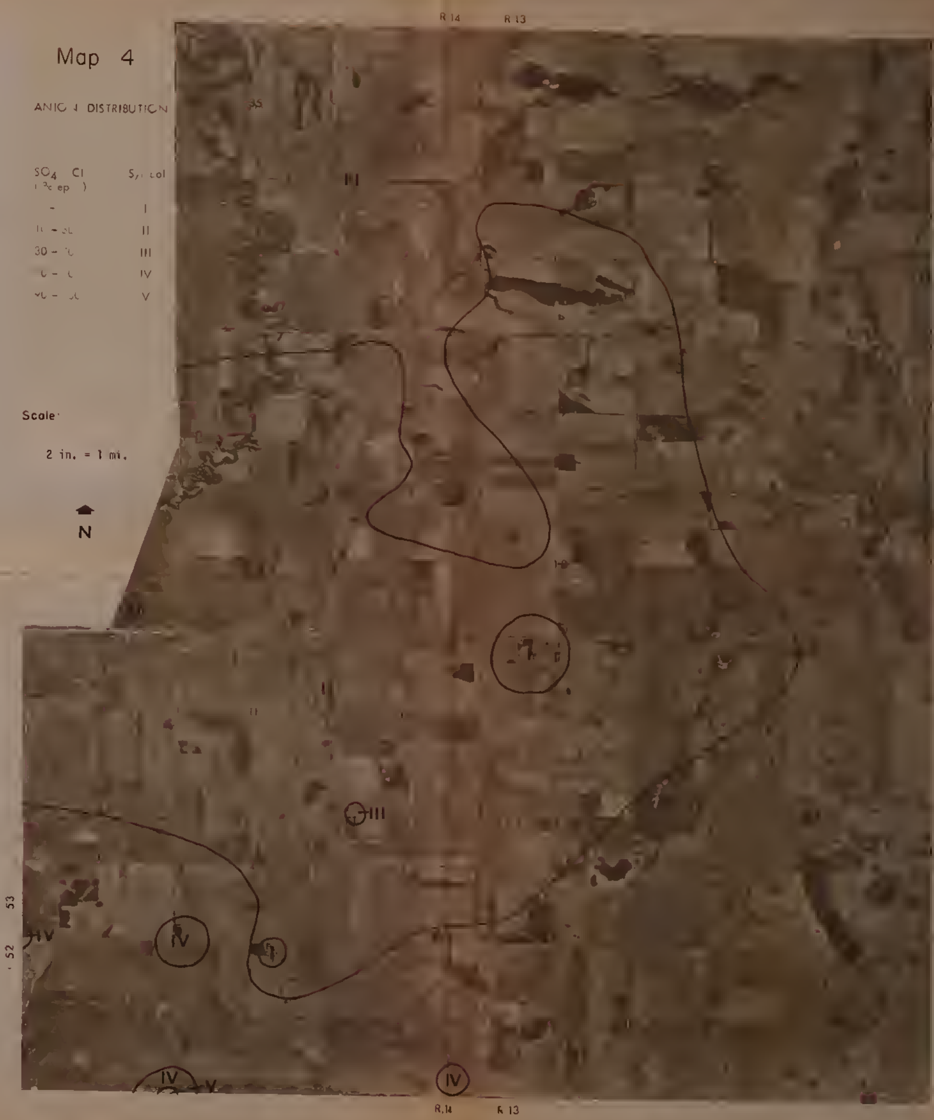


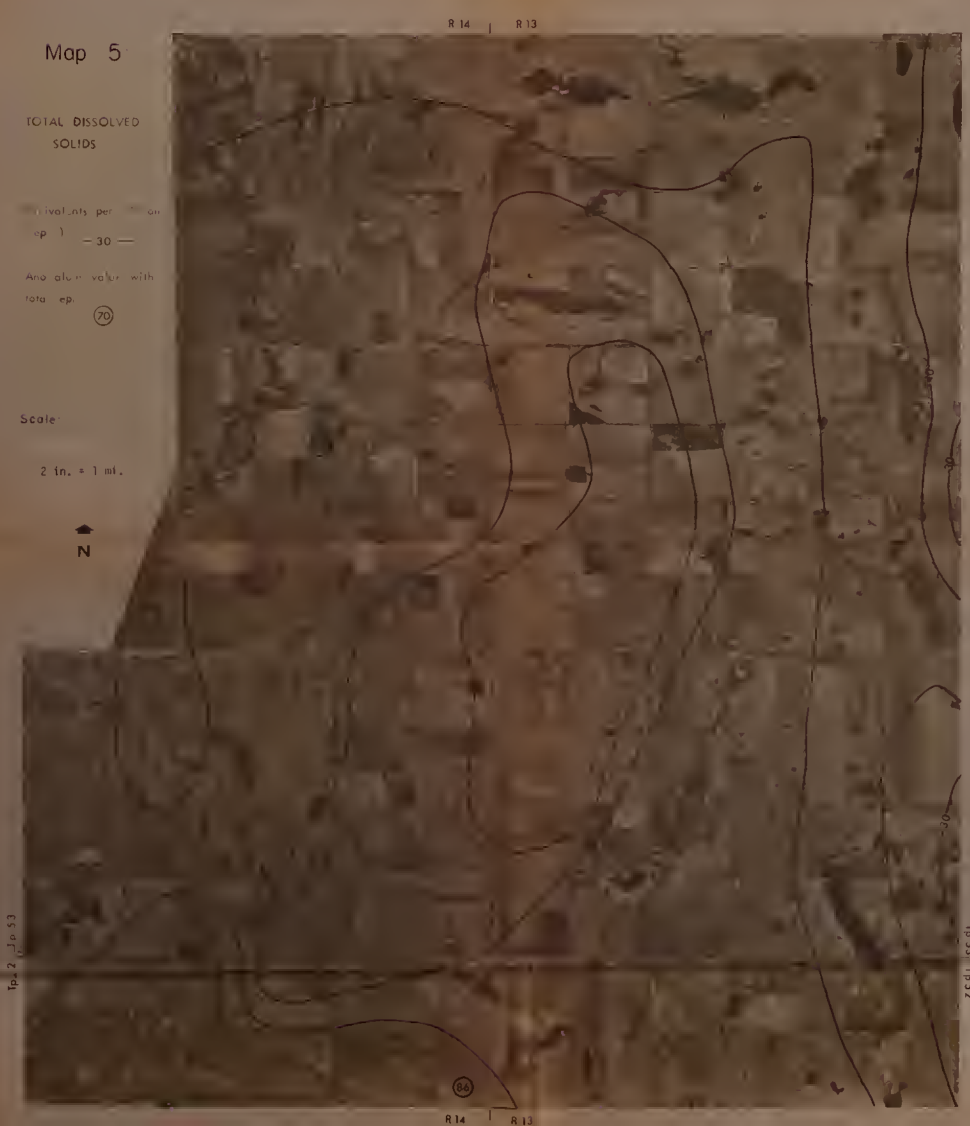
MAP 1. GEOLOGICAL MAP

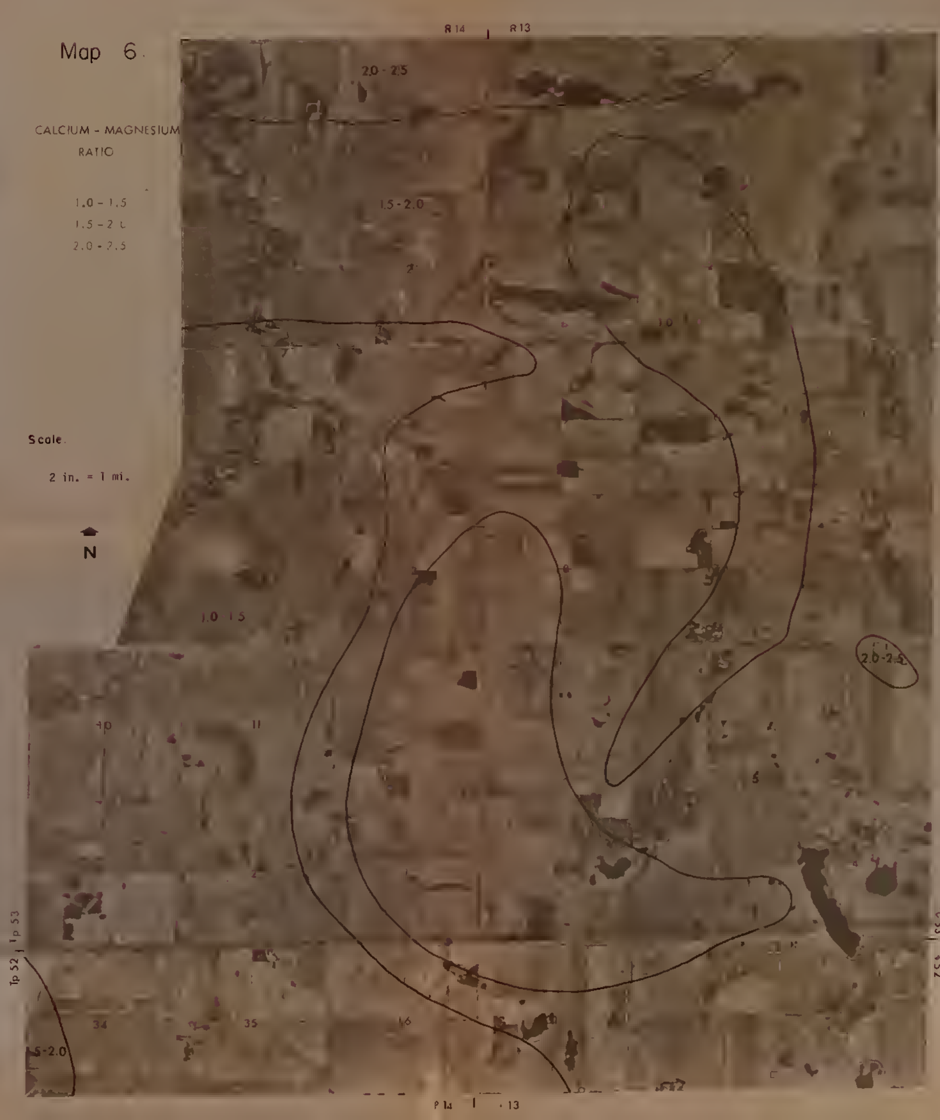
MAP 2: TOPOGRAPHICAL MAP

GROUNDWATER CHEMISTRY MAPS

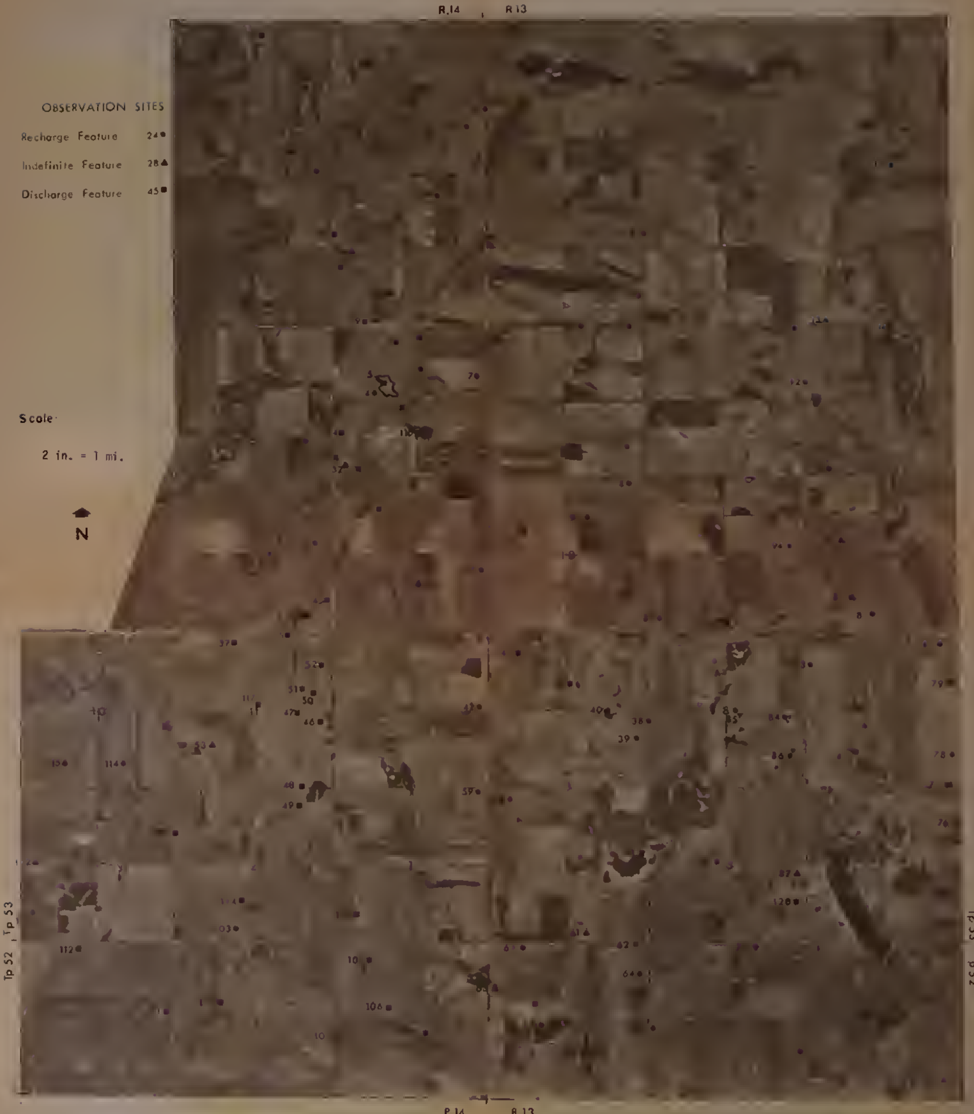








Map 7
SURFICIAL GROUNDWATER FEATURES



Map 8

AREAS OF GROUNDWATER RECHARGE AND DISCHARGE

Map 9:

SOIL MAP

SOIL LEGEND

ORDER	GREAT GROUP	SUBGROUP NAME	SYMBOL
Chernozemic	Black	Eluviated Black	1
		Carbonated Eluviated Black	[illegible]
		Gleyed Eluviated Black	[illegible]
		* (Truncated) Eluviated Black	1h
		Rego Black	[illegible]
		Saline Rego Black	2a
		Carbonated Rego Black	2b
		Saline Carbonated Rego Black	2d
		Saline Gleyed Rego Black	2e
		Carbonated Gleyed Rego Black	2f
		Saline Carbonated Gleyed Rego Black	2g
		(Cumulic) Rego Black	2i
		Solodic Black	3
Solonetzic	Solonetz	Black Solonetz	4
		Carbonated Black Solonetz	4b
		Gleyed Black Solonetz	4c
		(Thin) Black Solonetz	5
		Carbonated (Thin) Black Solonetz	5b
		Gleyed (Thin) Black Solonetz	5c
		Carbonated Gleyed (Thin) Black Solonetz	5f
	Solod	Black Solod	[illegible]
Gleysolic	Humic Gleysol	Orthic Humic Gleysol	
		Saline Orthic Humic Gleysol	a
		Carbonated Orthic Humic Gleysol	b
		Carbonated Saline Orthic Humic Gleysol	d
		Rego Humic Gleysol	[illegible]
		Saline Rego Humic Gleysol	9a
		Carbonated Rego Humic Gleysol	b
		Carbonated Saline Rego Humic Gleysol	d
	Eluviated Gleysol	Humic Eluviated Gleysol	
		Low Humic Eluviated Gleysol	[illegible]
Regosolic	Regosol	Saline (Carbonated) Orthic Regosol	11d
		Saline (Carbonated) Gleyed Regosol	11[illegible]
Permanent Lake			w

* Subgroup Modification ( )

TOPOGRAPHIC CLASSES

TOPOGRAPHY	% SLOPE
a	0.0 - 0.5
b	0.5 - 2
c	2 - 5
d	5 - [illegible]
e	[illegible] - 15

PARENT MATERIALS

DEPOSIT	SYMBOL
Till	———
Till and Sorted Material	- - - -
Alluvium	. . . .

Each group consists of - $\dfrac{\text{Dominant Soil - Associated Soil(s)}}{\text{Dominant Topography (Subdominant Topography)}}$ ← Parent Material

Example $\dfrac{1-4}{b-c}$ represents Eluviated Black - Black Solonetz developed on Till and Sorted Material with b and c Topography

Section No. 2

Scale - Approximately 3 1/2 inches equals 1 mile